JOURNAL of the AMERICAN WELDING SOCIETY

Vol. 10
No. 4
APRIL
1931

WM. SPRARAGEN
Editor

AMERICAN WELDING SOCIETY

EDITORIAL AND BUSINESS OFFICES

33 West 39th St.
New York, N. Y.

Discussion of Papers

Written and oral discussion of the Annual Meeting papers are invited by the Meetings and Papers Committee.

Through such discussion contentions by authors may be explained and improved as a result of the combined wisdom and experience of other members of the Society. Discussion of papers by those experienced is an opportunity and a responsibility on the part of all members.

BOUND VOLUMES

Bound volumes of the Journal for the year 1930 are now available in attractive imitation black leather covers. This volume contains a wealth of information on all phases of welding. Price per copy $5.00. Subject and Authors' Indices permitting easy reference are included. A few bound volumes for the years 1924-to-date, are still available at $5.00 per copy.

CONTENTS

Society and Related Activities — Page

Discussion of Papers 1
Program Annual Meeting 3
Authors of Annual Meeting Papers 4
Welding Symposium at Lehigh University 57
Welded Boiler Drums 57
Section Activities 57
Services Available 58
Fall Meeting American Welding Society 61

Technical Papers, Items and Reports

Some Resistance Welding Problems, by C. L. Pfeiffer 5
The Welded Boiler Drums of the U. S. Navy Scout Cruisers, by J. C. Hodge 11
Some Examples of Welding in Structural Steel Work, by D. C. Tennant 16
The Effect of Welding Procedure on Shrinkage Strains in Butt Welded Joints, by C. H. Jennings 27
Welder on Ships, by F. J. Fitz Gerald 30
The Metal Arc Welding of Copper Alloys, by Ira T. Hook 31
Ornamental Iron Work in Demand, by R. W. Boggs 37
Welded Machinery Foundations for Ships, by G. H. Moore, Jr. 38
Tender Underframes Lengthened by Welding, by E. V. David 42
Eccentric Welded Connections, by Odd Albert 43
Fusion Welding as Applied to High Pressure Heat Exchange Apparatus, by Marselis Powell 51
Current Welding Literature 55

Copyright, 1931, by the American Welding Society.

Subscription $5.00 per year in United States and Canada; Foreign Countries, $10.00; Foreign Libraries, $6.00.

The Society is not responsible for any statement made or opinion expressed in its publications. Permission is given to reprint any article after its date of publication, provided proper credit is given.

American Welding Society

OFFICERS FOR 1930-31

President
E. A. Doyle

Senior Vice-President
F. P. McKibben

Treasurer
C. A. McCune

Secretary
M. M. Kelly

Divisional Vice-Presidents
C. W. Babcock, New York & New England
J. S. Beall, Pacific Coast
W. W. Barnes, Middle Eastern
H. A. Wooster, Middle Western
George Bird, Southern Division

DIRECTORS

(Officers listed above are also members of the Board of Directors)

Term Expires 1931
A. M. Candy
J. H. Deppeler
E. H. Ewertz
F. M. Farmer
P. W. Swain

Term Expires 1932
C. A. Adams
H. M. Hobart
A. G. Oehler
J. W. Owens

Term Expires 1933
J. J. Crowe
W. H. Gibb
F. T. Llewellyn
H. S. Smith
W. C. Swift

Section Representatives
R. H. Atkinson
D. H. Detoe
A. E. Gaynor
P. E. Jeffers
H. D. Kelley
J. A. McCullough
F. L. Rodgers
W. A. Slack
L. C. Thomas
R. D. Thomas
H. A. Wooster
T. Wry

PAST-PRESIDENTS

C. A. Adams (1919-20)
J. H. Deppeler (1920-21)
S. W. Miller (1921-22)
C. A. McCune (1922-23)
T. F. Barton (1923-24)
E. H. Ewertz (1924-25)
A. G. Oehler (1925-26)
F. M. Farmer (1926-28)
F. T. Llewellyn (1928-30)

CHAIRMEN, STANDING COMMITTEES

Executive
E. A. Doyle

Finance
C. A. McCune

By-Laws
A. M. Candy

Meetings and Papers
P. W. Swain

Membership
A. E. Gaynor

Editor Journal, W. Spraragen

SECTION OFFICERS AND HEADQUARTERS

PHILADELPHIA—Engineers' Club, 1317 Spruce St.
Chairman—J. J. Dunne, Paschall Oxygen Co., 73rd St. and Woodland Ave., Philadelphia, Pa.
Secretary—H. E. Hopkins, 709 W. Huntington St., Philadelphia, Pa.

CHICAGO—608 So. Dearborn St.
Chairman—C. B. Evans, Western Electric Co., Hawthorne Station, Chicago, Ill.
Secretary—M. S. Hendricks, The Acetylene Journal, 608 So. Dearborn St., Chicago, Ill.

PITTSBURGH—Minnotte Bros. Co., House Building, Room 1201
Chairman—Leroy Gurley, Steel Publications, Inc., 108 Smithfield St., Pittsburgh, Pa.
Secretary—Joseph Minnotte, Minnotte Bros., House Bldg., Pittsburgh, Pa.

NEW YORK—33 West Thirty-Ninth St.
Chairman—T. C. Fetherston, The Linde Air Products Company, 205 East 42nd St., New York
Secretary—A. F. Keogh, Sound Welding Company, 905 East 134th St., New York

NORTHERN NEW YORK—General Electric Co., Schenectady, N. Y.
Chairman—L. R. Beers, General Electric Co., Schenectady, N. Y.
Secretary—F. M. Jefts, General Electric Co., Schenectady, N. Y.

CLEVELAND—Engineer's Room, Carnegie Hall
Chairman—J. F. McCullough, General Electric Company, Union Trust Co. Bldg., Cleveland, Ohio
Secretary—E. T. Scott, Cleveland School of Welding, Inc., 2261 East 14th St., Cleveland, Ohio

SAN FRANCISCO—Park Ave. & Halleck St., Emeryville, Cal.
Chairman—C. A. Britton, Central High School, Oakland, Cal.
Secretary—H. W. Saunders, Air Reduction Sales Co., Park Ave. & Halleck St., Emeryville, Cal.

LOS ANGELES—816 West 5th St., Room 603
Chairman—Paul E. Jeffers, Consulting Engineer, 816 West 5th Street, Los Angeles, Cal.
Secretary—Eric Barnett, Research Engineer, Columbia Steel Company, Los Angeles, Cal.

BOSTON—Engineering Societies of Boston, 715 Tremont Temple
Chairman—H. P. Peabody, J. A. Roebling's Sons Co., 93 Pearl Street, Boston, Mass.
Secretary—H. D. Large, 102 High Street, Malden, Mass.

WESTERN NEW YORK—500 Morgan Bldg., Buffalo, N. Y.
Chairman—J. N. Wilson, Republic Steel Co., 475 Abbott Road, Buffalo, N. Y.
Secretary—G. W. Swan, J. A. Roebling's Sons Co., 500 Morgan Bldg., Buffalo, N. Y.

DETROIT—Detroit Edison Company
Chairman—C. A. Bowlus, Chrysler Motor Corp., Highland Park Plant, Birmingham, Mich.
Secretary—M. P. Bailey, Detroit Edison Co., 2000 Second Ave., Detroit, Mich.

PORTLAND, ORE.—Associated General Contractors, care Multnomah Hotel
Chairman—Ray I. Smythe Willamette Iron & Steel Works, Portland, Ore.
Secretary—G. B. Herington, care Associated General Contractors, Multnomah Hotel, Portland, Ore.

CANADIAN—933 Bay St., Toronto
Chairman—Fred H. Williams, Canadian National Railways, Montreal, Canada
Secretary—Campbell Bradshaw, Executive Editor, Engineering Times, 933 Bay St., Toronto, Canada

---

AMERICAN BUREAU OF WELDING

(RESEARCH DEPARTMENT OF SOCIETY)

OFFICERS

Director
C. A. Adams

1st Vice-Director
H. L. Whittemore

2nd Vice-Director
H. M. Hobart

Secretary
Wm. Spraragen

CHAIRMEN, RESEARCH COMMITTEES

Welded Rail Joints
G. K. Burgess

Structural Steel
L. S. Moisseiff

Fundamental Research
H. M. Hobart

Welding Wire Specifications
C. A. McCune

Pressure Vessels
E. H. Ewertz

Standard Tests for Welds
F. M. Farmer

JOURNAL OF THE AMERICAN WELDING SOCIETY

VOLUME X APRIL, 1931 NUMBER 4

PROGRAM

Annual Meeting of the

AMERICAN WELDING SOCIETY

APRIL 22, 23, 24, 1931

ENGINEERING SOCIETIES BUILDING
33 West 39th Street, New York

IMPORTANT NOTICE

Members and their guests are requested to register
All Sessions Start Promptly as Scheduled

Wednesday, April 22, 1931

Morning

BUSINESS AND TECHNICAL SESSIONS

10:00 A.M. to 10:30 A.M., Room 2, 5th Floor, Business Meeting, E. A. Doyle, President, presiding.

Report of President, Report of Tellers' Committee, Election of Officers.

10:30 A.M. to 12 Noon, Room 2, 5th Floor, Technical Session, C. W. Obert, Chairman, Welding Conference Committee, presiding.

SHIPBUILDING

"Welded Boilers for U. S. Navy Scout Cruisers," by J. C. Hodge, Barberton Works, Babcock and Wilcox Company.

"Welded Machinery Foundations for Ships," by G. H. Moore, Jr., Newport News Shipbuilding and Dry Dock Company.

Afternoon

TECHNICAL SESSION—STRUCTURAL STEEL

2:00 P.M. to 5:00 P.M., Room 2, 5th Floor, H. M. Priest, Vice-Chairman, Structural Steel Welding Committee, presiding.

"Some Examples of Welding in Structural Steel Work," by D. C. Tennant, Structural Engineer, Dominion Bridge Company.

"Formulæ for Eccentrically Welded Connections," by Odd Albert, Bridge Designer, New Jersey Highway Commission.

"Some Tests of Gas Welded Structural Joints," by H. H. Moss, Linde Air Products Co.

Evening

BOARD OF DIRECTORS' MEETING

6:30 P.M., Dinner Meeting, Board of Directors' Meeting, Hotel New Yorker.

Meeting of Board of Directors of American Welding Society. Appointment of Committee Chairmen and other Officers. Committee reports. Plans for the coming year.

Thursday, April 23, 1931

Morning

TECHNICAL SESSION

10:00 A.M. to 12 Noon, Room 2, 5th Floor, E. H. Ewertz, Past President, presiding.

"Some Resistance Welding Problems," by C. L. Pfeiffer, Western Electric Company.

"The Effect of Welding Procedure on Shrinkage Strains in Butt Welded Joints," by C. H. Jennings, Westinghouse Electric & Manufacturing Company.

"Fusion Welding as Applied to High Pressure Heat Exchangers," by Marselis Powell, Whitlock Coil Pipe Company.

Afternoon

TECHNICAL SESSION—PIPING

2:00 P.M. to 5:00 P.M., Room 2, 5th Floor, W. H. Ludington, Manager, Applied Engineering, Air Reduction Sales Company, presiding.

Joint meeting with Pressure Piping Code Committee of American Standards Association. Presentation and discussion of proposed section of code dealing with welding of pressure piping by subcommittee of the American Welding Society.

"Welding of Heating and Industrial Piping," by J. H. Zink, Chairman, Committee on Welding, Heating and Piping Contractors National Association.

Evening

TENTH ANNUAL DINNER

6:30 P.M.

Hotel New Yorker
34th St. and 8th Ave.

The dinner, as last year, will be arranged as a stag affair. Exceptional entertainment has been provided by the Dinner Committee. There will be no speakers.

Friday, April 24, 1931

Morning

TECHNICAL SESSION

10:00 A.M. to 12 Noon, Room 2, 5th Floor, A. G. Oehler, Past President, presiding.

"Thermit Welding in Maintenance in the Steel Mill," by J. H. Deppeler, Chief Engineer, Metal and Thermit Corp.

"Metal Arc Welding of Copper Alloys," by Ira T. Hook, American Brass Company.

"High Tensile Atomic Hydrogen Arc Welds in Alloy Steels," by Frederick Ray, Consulting Engineer, Croll-Reynolds Engineering Company.

Friday, April 24, 1931 (Continued)

Afternoon

STRUCTURAL STEEL WELDING COMMITTEE
AND
AMERICAN BUREAU OF WELDING

1:45 P.M. to 4:00 P.M., Room 2, 5th Floor, Meeting of Structural Steel Welding Committee, L. S. Moisseiff, Chairman.

All members of the Society are cordially invited.

A report and analysis of test data will be presented by the Structural Steel Welding Committee.

4:00 P.M. to 5:00 P.M., Room 2, 5th Floor, Annual Meeting of American Bureau of Welding, C. A. Adams, Director, presiding.

Report of progress made by various research committees of the Bureau. Election of Officers. Appointment of Executive Committee.

Saturday, April 25, 1931

INSPECTION TRIP

A very interesting inspection trip has been arranged to the New York Hospital and Cornell Medical Center. Mr. C. Kandel is in charge of the general arrangements.

Members of the Society and their guests will assemble at East 70th Street, between York Avenue and East River, promptly at 10:30 A.M. The visitors will be divided into groups of from twelve to fifteen as fast as they arrive, placed in charge of competent guides and taken through the main building and power house where they will have an opportunity of observing the layout of the work, as well as welded joints of various types in different stages of completion. This project involves over 50,000 feet of welded piping ranging in size from 2½" to 24" for transmission of hot water, brine and steam for low pressure and high pressure service. The heating contractor for the main building is the Almirall & Co., Inc., and the heating contractor for the power house is T. F. Hall, Inc.

Authors of Annual Meeting Papers

There follows a brief biography of some of the authors who will present papers before the Annual Meeting:

Odd Albert, author of the paper on "Formulæ for Eccentrically Welded Connections," is a graduate civil engineer with a M. S. degree. He had six years of European experience including an appointment as professor of mathematics at West College. He has published a book with "first and second editions." He came to this country in 1925 and has been connected with the New England Structural Company, the Aberthaw Company and with Dwight P. Robinson, who was one of the head designers of the North Station project, and he has also been connected as designing engineer of the Stone & Webster Company and as assistant engineer of the New York Central R. R. Mr. Albert is a member of the Royal Swedish Engineers Club, Stockholm; the Swedish University Club, Boston, and the American Society of Swedish Engineers, Brooklyn. He was president of the Swedish University Club, 1928-29. He has published several articles in *Civil Engineering* and has reviewed Scandinavian books for the *Engineering News-Record*. He is also an abstractor-editor for the *Journal of American Concrete Institute*.

J. H. Deppeler, author of the paper on "Thermit Welding in Maintenance in the Steel Mill," is chief engineer and works manager of the Metal and Thermit Corporation. After being graduated from the Stevens Institute of Technology in 1906 with the degree of mechanical engineer, he was associated with the New York Central Railroad in the electrification of its New York terminal. In 1909 he became interested in acetylene welding and worked in the research and development of this until 1912, when he became associated with the Goldschmidt Thermit Company, now the Metal and Thermit Corporation, New York. He is a Past President of the American Welding Society.

Ira T. Hook, author of the paper on "Metal Arc Welding of Copper Alloys," graduated from the University of Michigan in 1913. Prior to entering the university he worked at machinist's trade from 1901 to 1908. He was physical test expert for General Motors Corporation 1913 to 1920, except for service as first lieutenant in U. S. Army 1917 and 1918. He taught strength of materials at Yale University in 1920 to 1923. In 1924 he entered the service of the American Brass Company, with which company he is still connected. Since 1925 he has been specializing in the welding of copper alloys.

C. H. Jennings, author of the paper on "The Effect of Welding Procedure on Shrinkage Strains in Butt Welded Joints," was graduated from the mechanical engineering department of Iowa State College with a degree of Bachelor of Science in M. E. During 1928 he was a graduate student at Westinghouse Electric & Mfg. Co. and later became connected with the Mechanics Division of the Westinghouse Research Laboratories. Since joining the Research Laboratories his efforts have been confined to the fundamental investigation of the physical properties of arc welds. He is a Junior Member of the American Society of Mechanical Engineers, an Associate Member of the American Welding Society, and chairman of a Welding Society Committee for the Revision of the Bulletin on Fundamentals of Electric Arc Welding.

G. H. Moore, Jr., author of the paper on "Welded Machinery Foundations for Ships," is staff supervisor of welding at the Newport News Shipbuilding & Dry Dock Company. His principal work is welding development, design and research. His experience has been shop, inspection, erection and design, and he was assistant in hull welding design in the Welding Research Department from 1926 to 1930. He is a member of the Welding in Marine Construction Committee and its sub-committee on Hull Construction, of the American Welding Society.

C. L. Pfeiffer, author of the paper on "Some Resistance Welding Problems," graduated from the University of Illinois with the degrees B. S. and E. E. Among the companies with which he has been connected may be numbered The Pullman Car & Manufacturing Corp., Automatic Electric Co., Michigan State Telephone Co., Transit Construction Commission of New York, Oklahoma Gas & Electric Co. and the University of Cincinnati. During the war he served as liaison officer of the 70th Field Artillery. His present position is electrical engineer on welding and electrical studies in the Manufacturing Branch at the Hawthorne Plant of the Western Electric Company.

Marselis Powell, author of the paper on "Fusion Welding as Applied to High Pressure Heat Exchangers," became connected with welding in 1920 at the plant of the General Electric Company at Schenectady. Prior to this he attended Union College at Schenectady, and left the university to become a member of the Navy during the World War. At the General Electric Company he went through the arc welding school and was employed as demonstrator of hand and automatic arc welding equipment. In 1925 he joined the forces of the Whitlock Coil Pipe Company at Hartford as arc welding foreman. In 1928 he was made general foreman of the plant, which position he now holds.

(*Continued on page* 57)

Some Resistance Welding Problems

By C. L. PFEIFFER

✦ This paper is to be presented at the Annual Meeting of the A. W. S., by C. L. Pfeiffer, Engineer in Charge of Welding Development, Western Electric Company, Hawthorne Plant.

Synopsis

THE purpose of this paper is the discussion of certain fundamental concepts in the art of resistance welding to assist in the determination of their applicability to specific problems in the design and manufacture of apparatus assemblies, machinery, and other products. The subject matter indicates the factors to be considered in adapting problems to certain fixed conditions. The welding of non-ferrous materials is stressed because they are more difficult as a class to weld than the ferrous groups. A description of some interesting resistance welding processes in use at the Hawthorne Plant of the Western Electric Company is included in the latter half of the paper.

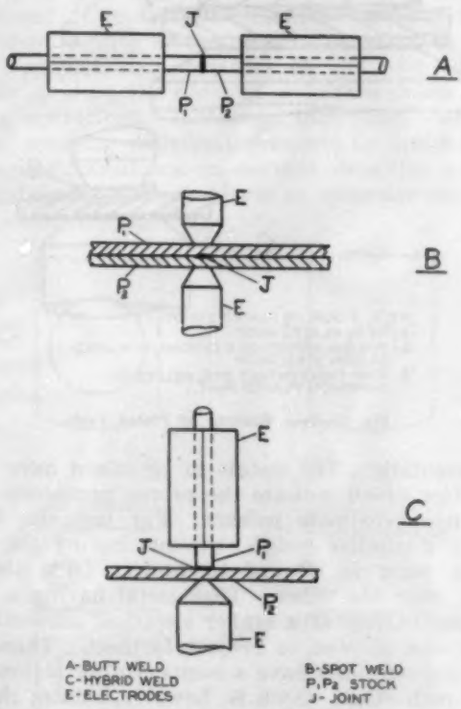


Fig. 1—Types of Welded Joints

Electric resistance welding was conceived and developed to a commercial status by Professor Elihu Thomson. The first welding patent issued to him was dated Aug. 10, 1886. Since that time many other patents have been issued in connection with this process covering further machine developments or refinements in operating technique. In principle welding is the same as the method used by blacksmiths in uniting metals. Instead of heating parts locally in a forge, they are heated by means of an electric current, which is restricted to the area to be fused either by means of electrodes or the contact surfaces of the parts to be welded. If the energy input at the joints, represented by I^2R x time, is sufficient to bring the materials to a plastic stage, the parts may be fused together by the application of pressure.

Practically all metals or combinations of metals may be joined by the resistance welding process. Welding means actual fusing together of the parts being joined. Very often a joint is called a weld when it is only a mechanical union produced on a welding machine. Joints of this type may be satisfactory for a specific purpose, but care should be exercised to distinguish between a mechanical joint and a true weld.

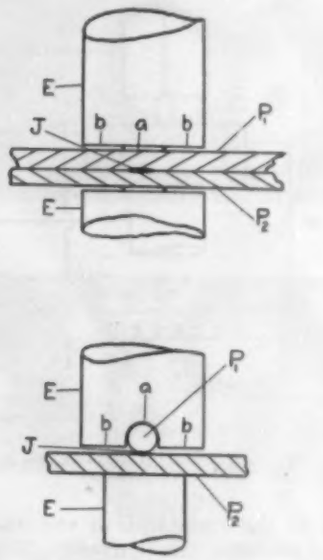


Fig. 2—Special Electrodes

Joints made by the resistance welding process may be grouped under three general headings: butt, spot, and hybrid joints. These are shown in Fig. 1, and are listed as "A," "B," and "C," respectively. "P"$_1$ and "P"$_2$ are the parts to be welded, "J" indicates the joint. In a butt welded joint, round or rectangular rods, P_1 and P_2 are gripped between welding jaws and the extending ends fused together. In a spot welded joint, two or more sheets, P_1 and P_2 are held together by two electrodes and fused locally between the electrodes. In the hybrid joint shown at "C," Fig. 1, P_2 is backed by a spot welding electrode, and P_1 is gripped by a butt welding electrode. The hybrid joint is the most difficult of the three and should be avoided if possible. In all three types of joints, each pair of electrodes usually includes a stationary and a movable member.

The following list indicates the factors to be considered and coordinated when attempting a resistance welded joint.

1. Current density per unit area.
2. Time of current cycle.
3. Pressure per unit area.
4. Electrical conductivity of the parts being welded.
5. Heat conductivity of the parts being welded.
6. Specific heat of the parts being welded.
7. Melting points of the materials.
8. Medium in which joint is to be made.

9. Cooling stresses.
10. Heat of fusion.
11. Contact resistance.

The elements usually considered in resistance welding are current, pressure, and time. The function of the current is simply to bring the points to be joined to the proper fusing temperature. The resistance of the path through which the current flows multiplied by the square of the current and the time of application in seconds gives the total energy input. As the parts heat up the resistance of the material increases, tending to decrease the current. However, a better contact is usually made as the weld progresses so that the original contact resistance is reduced. If the parts to be joined are made of the same material and are arranged in a symmetrical manner, similar to that used in a butt or spot weld, both parts will reach a welding heat at the same time. When this plastic stage is attained it is simply a matter of applying the proper pressure to insure a good joint.

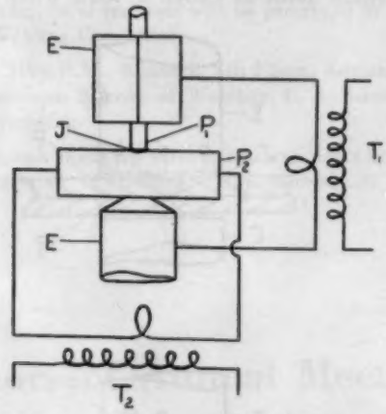


Fig. 3—Welding Circuit with Pre-Heating Transformer

If, however, either unlike materials or like materials are to be fused into a hybrid joint, or unlike materials are to be fused into a butt or spot welded joint, then the electrical and heat conductivity, the specific heat, the melting point, and heat of fusion of each material used should be taken into account. The problem resolves itself into the establishment of heat balances as the parts must both reach a temperature where they will readily fuse or alloy with each other simultaneously.

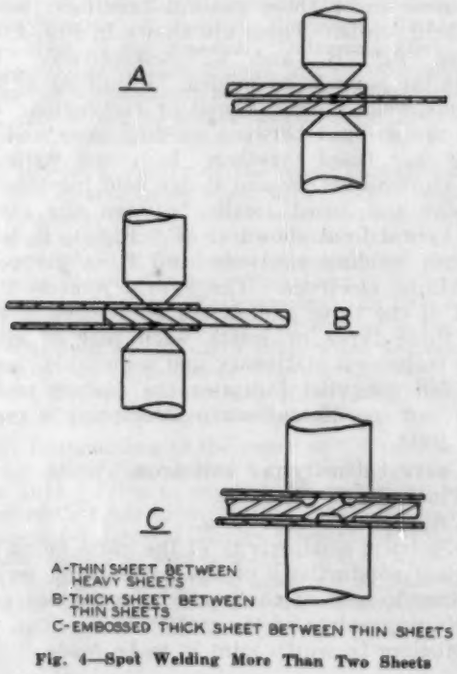


Fig. 4—Spot Welding More Than Two Sheets

The exact heat balance can usually be determined experimentally. The metals to be joined have certain properties which indicate the proper procedure to provide an approximate balance. For instance, in butt welding dissimilar metals, the one having the higher melting point is allowed to project from the jaws farther than the other. That metal having a higher heat conductivity or a higher electrical conductivity is usually also allowed to project farthest. These properties may at times have a compensating action in opposing each other, which is, however, seldom the case. For instance, copper and aluminum have relatively higher electrical and heat conductivities, higher specific heats and higher melting points than tin and nickel silver.

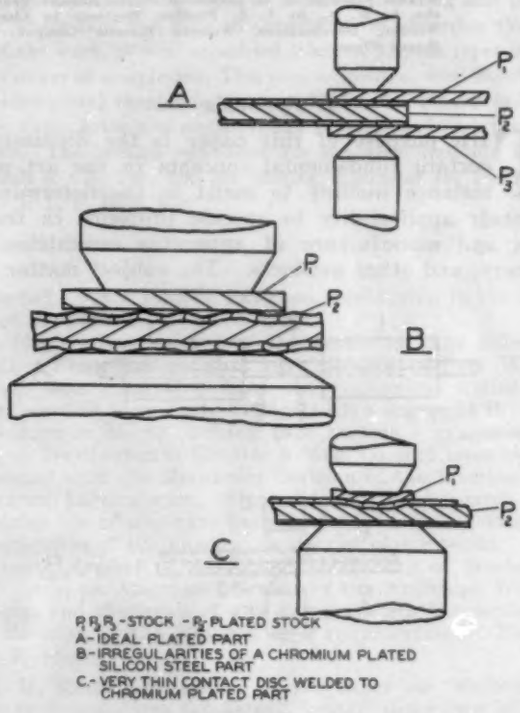

A
B
C
P1P2P3 - STOCK - P2 PLATED STOCK
A - IDEAL PLATED PART
B - IRREGULARITIES OF A CHROMIUM PLATED SILICON STEEL PART
C - VERY THIN CONTACT DISC WELDED TO CHROMIUM PLATED PART

Fig. 5—Spot Welding of Plated Parts

In spot welding dissimilar sheets a heat balance may be procured by varying the size of electrode tips or the electrode material. If copper electrodes are used a much greater amount of heat is conducted from the weld area by an electrode having a larger surface contact than one having a small surface contact. Similarly the electrode having a larger bulk behind its contact surface tends to draw heat from the point of contact. In order to concentrate heat applications, small electrode surfaces and electrode materials having lower heat conductivities and higher melting points than copper are used. For example, in welding a sheet of copper to a sheet of iron the use of a tungsten electrode against the copper and a copper electrode against the iron is recommended.

In making miscellaneously shaped hybrid joints each case should be closely analyzed. It is quite obvious that in a joint similar to "C" in Fig. 1, part P_1 will tend to become hotter than P_2. One remedy for this unbalance is the use of a small contact area on the electrode against P_2 and arranging P_1 to project only a small amount from a large contact surface electrode. Furthermore, in choosing materials it will be advantageous for P_1 to have either a higher melting point, higher electrical conductivity, higher heat conductivity, higher specific heat, or higher heat of fusion. It is possible, of course, to overstep the balance point and have even the larger part of P_2 get hotter than P_1. Such a condition would be rare, however. Each case is usually resolved into a choice of doing only one of several things to bring the parts to be fused to the proper welding temperature at the proper time.

Although the pressure on the movable electrode usually serves to force the plastic parts together, there are other functions this movement may cover. The initial contact pressure determines the amount of contact resistance and consequently limits the first rush of current. The initial pressure may also determine the amount of contact surface and thereby determine the current density at the point of contact. It is very difficult to distribute pressure equally over irregular surfaces or along the edges of wide thin sheets in butt welding operations. It follows that joints having an unequal pressure distribution should be avoided, since this causes variations in current densities per unit area and consequently produces an irregular and poorly fused joint.

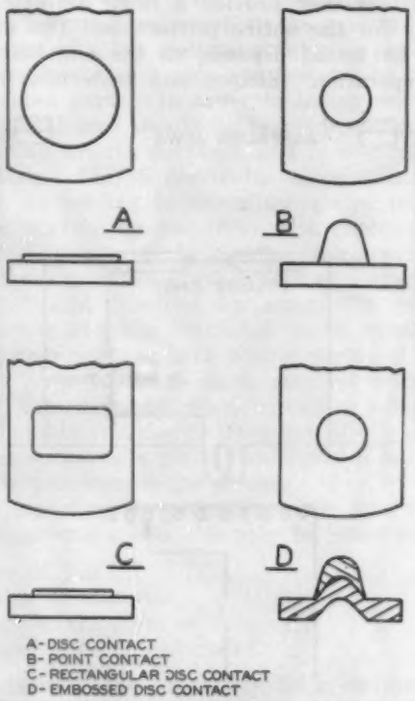


Fig. 6—Precious Metal Point and Disc Contacts

The pressure on the movable jaw also determines the acceleration of this member after the parts become plastic. This is very important when high conductivity metals are being welded. In these cases a very high current is sent through the parts for a short time. If the parts are not free to move together quickly an arc blowout is produced, in which case either no joint or a very poor joint may result.

In many cases it is very important to have a nearly constant current. This is especially true when attempting difficult joints. An approximately constant current may be obtained by introducing a resistance or reactance ballast into the welding circuit. For light work a metallic shunt around the electrodes or immersion in a liquid will serve as ballast. Ballast not only tends to stabilize the current, but it is an effective means of dealing with variable contact resistances.

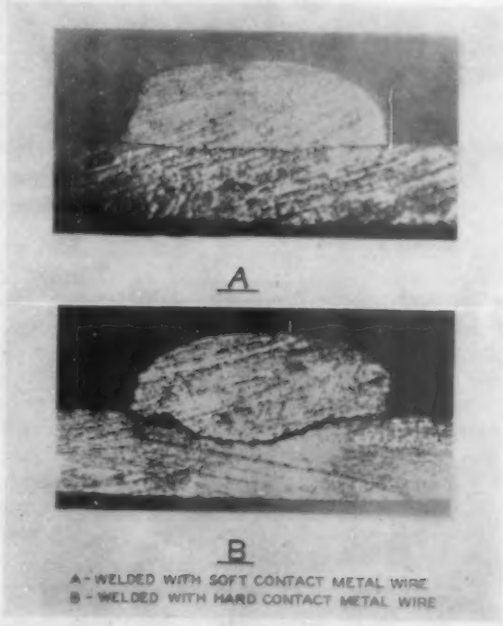


Fig. 7—Point Contact Micrographs

The design of electrodes is very important. Both the material and shape of the electrodes should be analyzed carefully. The most generally used materials are copper, tungsten, or alloys of copper and tungsten. Copper can be used in practically every case. Where wear is heavy it may be well to substitute harder alloys of copper and tungsten. These, however, become hotter than copper and are generally cooled by water chambers, air, or radiating wings. The tip contact area of the electrode determines the current density for spot welding operations. The current density may be varied during the welding cycle by electrodes shaped like those in Fig. 2. Part "a" makes contact at the beginning of the welding cycle, but after the parts compress and start to fuse, surfaces "b" make contact, thereby cutting down the current density below the welding requirement. This acts as an automatic stop at a critical point of the operation. Such electrodes are similar in action to projection welding methods, where a part of the material to be joined is embossed in order to localize the heat. As soon as the projection fuses into the part being welded the current density is greatly lowered, this action being similar to a current cut-off.

Sometimes the parts being joined have such dissimilar characteristics that it is impossible to provide the proper heat balance by changing material or modifying electrode shapes. In some such cases it is possible to preheat the part which tends to remain cooler by means of a separate transformer. Fig. 8 illustrates an extreme case of this kind. P_2 is either very large or has a high heat conductivity. The circuit is usually arranged so that part P_2 is brought to a near welding

heat by current from transformer T_2. At the instant that current from T_2 is cut off the welding current from T_1 is cut in. This insures perfect fusion if the current values and time of application are properly coordinated.

The use of more than one transformer per welding machine is closely related to the use of multiple electrodes. A number of simultaneous welds may be made

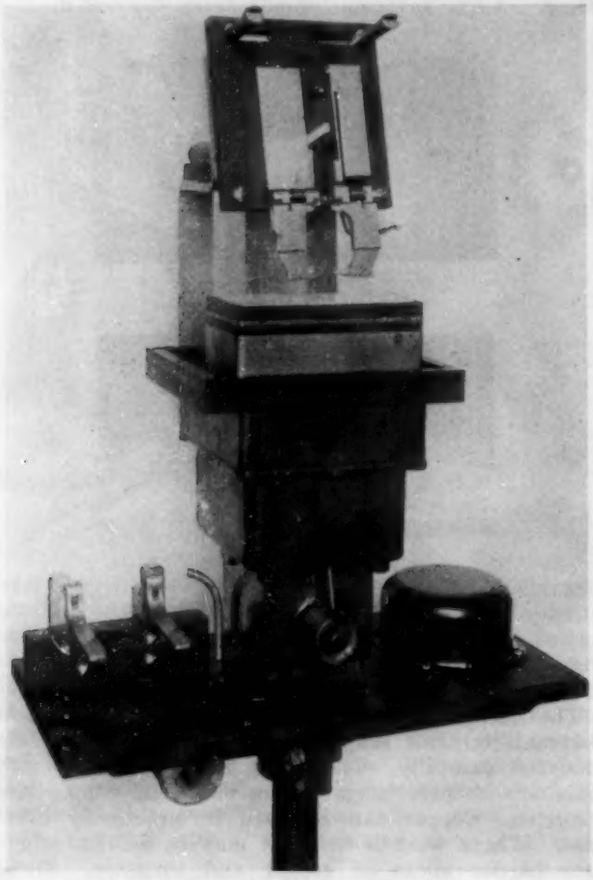


Fig. 8—Butt-Welder for .011" Permalloy Wire

by one transformer if the type of joint is simple and the material welds readily. If, however, the welding operation is at all critical it is advisable to provide one transformer for each joint. In such cases separate mechanical action should be provided for each electrode or the purpose of having separate transformers will be defeated. One transformer may provide current for more than one weld if the joints are arranged in a series set-up. In such cases the nature of the joint or the electrodes must be such that on the completion of the weld the current density is automatically decreased. This takes care of any irregularity in the time necessary to complete a good joint.

Although most metals join readily, some are more or less obstinate in their resistance to this operation. This may be illustrated by two hands. For example, the intertwining of fingers is similar to perfect fusion between the parts being welded and provides a satisfactory joint, usually as strong as the adjacent material. The two hands pushed against each other, fingers curved back, indicates the kind of joint often produced when the parts have no natural affinity for each other. Some of the permalloys, high carbon steels, chromium alloys, cobalt steels, and silicon steels may be classed as metals tending toward the latter type of joint. A test for fusibility is the welding of identically shaped parts under varying conditions of balance. If a poor joint results consistently, special accommodations are usually required. For instance, in butt welding a certain permalloy wire, a brittle, weak joint resulted. When immersed under carbon tetrachloride the joint became strong and tough, so that the wire could be reduced by drawing through dies without failure. This seemed to indicate that the liquid acted similar to a catalytic agent. A more thorough search into this matter should prove interesting.

Development of a rapid non-destructive method of testing resistance welds will eliminate a certain amount of uncertainty now prevalent in welding processes. This is especially true of non-ferrous joints where the welded parts must be very strong. The usual tests are destructive in nature. If the part fails at a point outside of the welded area, the joint is considered good. However, this test cannot be applied to parts that are to be used. A tension, compression, or shear test of a value slightly less than the average point of failure may weaken an otherwise good joint. If the force applied is relatively small, the test is of small value. A destructive test applied to a small percentage of the parts is the best method now available. If the parts are being welded on an automatic machine a mechanism may be included to test every tenth, hundredth, or thousandth joint to a value approximating failure, but not destructive. All of the tested parts should be segregated and treated as seconds and approximately ten per cent given a destructive test. If these results are consistent they provide a fairly reliable measure of quality for the entire production. The number of parts to be tested depends on the simplicity of the welding operation. Shapes and materials which are

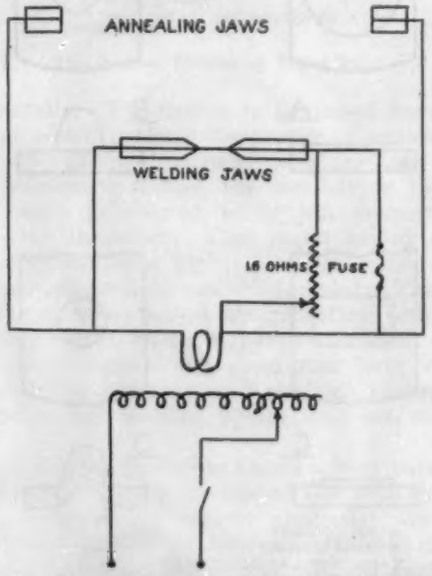


Fig. 9—Wiring Diagram of Permalloy Butt-Welder

easily welded require less inspection than those which are difficult to join.

A frequent problem is the spot welding of more than two sheets of either like or unlike materials. Fig. 4 gives some general examples of these joints. "A" shows a thin sheet between thick members and "B" shows a thick sheet between thin parts. For the same material type "A" welds are simpler to make than type

"B." The inside sheets heat up less rapidly because the current density is usually less. If, however, the center piece in "B" has a lower melting point, a lower heat conductivity, or a lower electrical conductivity than the outside pieces, the condition of balance facilitates production of a perfect joint. If, on the other hand, the center piece in "B" has a relatively higher melting point and higher heat and electrical conductivities the problem is very difficult. In this case it may be possible to localize the heat by using a high current density for a very short period. Other possibilities are the introduction of pellets, or a double circular embossing as shown in "C" of Fig. 4. In this type of joint the surface contact area of the upper and lower part of the embossing must be approximately equal.

The welding of plated parts is closely related to the spot welding of multiple sheets. A plated sheet really consists of the sheet material itself and two thin layers of the plating material on each face. "A" in Fig. 5 illustrates this condition, P_2 being the plated part. Closely balanced spot welds usually produce good joints under these conditions. Some trouble is presented by chromium plated parts because of the high melting point of chromium. The use of plated parts of dissimilar materials or hybrid joints of either similar or dissimilar materials usually increases the difficulties of welding plated parts materially. Irregularities in shape or differences in material characteristics may sometimes be used to great advantage. For instance, in spot welding platinum to a chromium plated part, the high melting point of chromium is advantageous. On the other hand, if the plated part has a very large bulk in comparison to the part to be welded to it, the use of a low melting point zinc plate is helpful. Plated parts as a rule are less apt to be smooth than unplated parts. In order to lessen welding difficulties, special care should be taken in cleaning parts, in developing smooth surfaces, and in controlling plating methods. Fig. 5 illustrates some difficulties encountered in welding to chromium plated parts. "B" shows the surface irregularities of a chromium plated silicon steel armature. In spot welding previous metal discs to these armatures, the points of contact produce different current densities for practically every weld. "C" indicates how the chromium plate remains intact after all other parts become plastic during the welding cycle. In some instances parts may be welded before plating. This may, however, introduce another difficulty, as minute crevices or irregularities in the welded area often accumulate plating salts which later emerge to discolor and corrode the parts.

Four important considerations in the design of welded apparatus assemblies may be listed as follows:

1. Type of joint.
2. Choice of material.
3. Shape at the point of welding.
4. Accessibility of electrodes.

These things have previously been discussed, but a brief repetition may emphasize their importance.

In choosing the type of joint every effort should be made to provide a perfectly balanced spot or butt weld. This will usually simplify every subsequent consideration, the most important of which is a choice of material. If it is necessary to use a hybrid joint care should be exercised to avoid extremes.

The most universally used materials for welding are iron and steel, although other materials are used extensively and successfully. The following tabulation lists the more generally used materials in the approximate order of their weldability:

1. Wrought Iron.
2. Low Carbon Steels.
3. Nickel.
4. Nickel Silvers.
5. Monel.
6. Bronze.
7. Galvanized Iron.
8. Permalloy.
9. High Carbon, Silicon, Cobalt, or Chromium Steels.
10. Duralumin.
11. Nichrome or Chromel.
12. Aluminum.
13. Copper.
14. Brass.
15. Zinc.
16. Lead.

The first consideration is the fusibility of the material. This is most easily determined by experimental butt or spot welds. For welds which join dissimilar materials or are hybrid in nature, a close inspection should be made of the heat and electrical conductivities and the melting points. A study of these characteristics will help one establish at least a near heat balance so that opportunities for perfect fusion are greatest.

Some materials have peculiar cooling characteristics after being subjected to the welding operation. Stresses may be set up which fatigue the joint, and although an immediate test shows the weld to be strong, tests made months later may demonstrate material weakening.

Shapes of the parts being welded and accessibility of the electrodes are closely related in welded apparatus design. The shape of the parts determines the type of weld to be employed which should be such that the joining process makes possible an easy heat balance. In order not to hamper production the electrodes must be made easily accessible to the point of fusion, even if this makes a heat balance more difficult. The parts and the welding fixtures should be designed so that the electrodes may be easily trimmed or replaced, and, if possible, to permit the use of standard designs.

In all welding operations the presence of grease, dirt, scale, or other foreign material causes trouble. Parts should be designed so that they may be dipped in cleaning solutions, tumbled, or sand blasted. This promotes constant factors in the welding operation and consequently speeds up production.

An important welding operation in the manufacture of communication apparatus is the welding of precious metal contacts to various relay and key springs. This method of assembly has replaced the old type platinum contact rivet and has saved a large percentage of contact metal formerly required in the rivet shank. In addition, the use of a point contact on one of a pair of springs and a disc on the other has simplified accuracy maintenance in both welding and assembly.

There are two types of semi-automatic machines in use at the Hawthorne Plant of the Western Electric Company for welding contacts of the type shown in Fig. 6. The point machine feeds the end of a precious metal wire through an electrode into contact with a nickel silver spring. At this point the welding current is applied to fuse the wire end to the spring. Immediately thereafter a cutter snips off the proper length of precious metal, following which a die forms the welded wire into the desired shape. On the disc machine precious metal tape is fed into a miniature punch and die and the proper sizes of contact discs are punched out. Fingers engage these discs and place them in the welding position between the welding electrodes. A forming hammer is also used on this machine to insure a smooth surface on the welded disc.

Efforts are being made constantly to save the costly contact metal. Methods for replacing parts of the

precious metal not used during the life of a piece of apparatus are always under consideration. Recently a method of embossing certain point contacts has gone into production. Fig. 6-"D" illustrates the contact produced by this method. The cycle of operation in making these contacts is the same as on the point welding machine. The cutters snip off less contact metal, but the embossing tool used in the forming operation raises the contact metal cap to the required height.

A study of point and disc contact alignment revealed that a rectangular contact could be substituted for this disc design. Sketch "C" in Fig. 6 compares the shape and size of this contact with the former type, shown in Sketch "A," Fig. 6. The new design is more difficult to weld because greater skill is required in dressing electrodes, but the saving in contact metal is substantial.

A recent investigation of precious metal shortages on point contacts revealed the extreme importance of

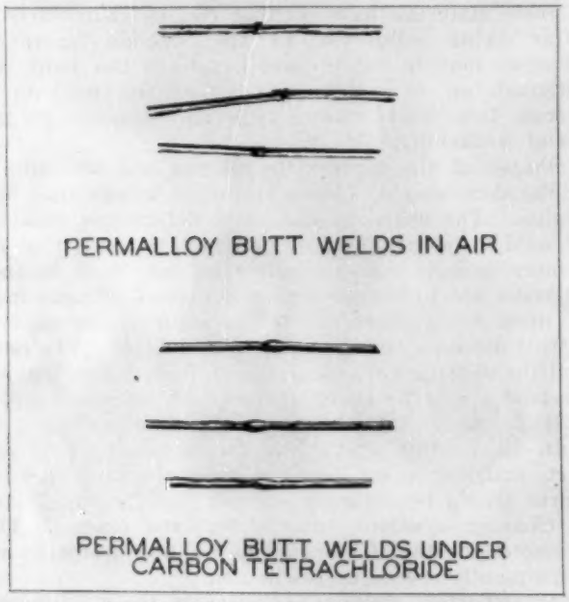


Fig. 10—.011" Permalloy Wire Butt-Welds

the shape of clipped ends. A soft contact metal point was being replaced with harder metal of the same shape. The wedge shaped cut used on the softer wire gave the welded cross-sectional area shown in "A," Fig. 7, and the harder wire gave a welded cross-section shown in "B." These differences could only be detected by microscopic examination. The wedge point of the harder wire was not flattened sufficiently when pressure was applied before welding, which reduced the contact area. Since the harder material also had a higher melting point, the wedge shape was retained during the welding cycle and the subsequent forming operation tended to drive the contact metal shape into the nickel silver spring. This condition was remedied by flattening the cut end of the wire so that each side of the wedge angle was reduced by 25 deg. The reduction in cutting angle made possible welded sections comparable to the softer metal shape.

A bench type punch press welder is used for welding multiple brush springs. Each spring consists of a piece of .015-in. nickel silver about ¼ in. wide, to which is welded a .025-in. brush shoe about .075 in. wide by ⅜ in. in length. Two welded joints are made at the same time at either end of the shoe, one a hybrid joint and the other a projection weld. The shoe is shaped like a zee-bar section which fits an offset portion of the nickel silver spring. The parts are placed in a special hinged welding fixture. A duplex joint is fundamentally difficult to make, and the problem was complicated by the addition of a fiber bushing between the bronze shoe and nickel silver spring. The fixture is placed between the copper electrode of the press and a foot pedal motion completes the subsequent welding operation.

Fig. 8 shows a butt-welder used in joining .011-in. permalloy wire under carbon tetrachloride. The jaw mechanism is made of monel and is of very light construction. The right jaw is movable and actuated by a vertical blade spring. Fig. 9 shows the wiring diagram of this welder. The secondary circuit has a resistance ballast in series with the welding jaws which serves both as a timer and a current tapering device. This resistance ballast is made up of a variable resistance of about 1.6 ohms and a .008-in.-2-in. nickel fuse connected in multiple. The wire ends are clamped in the welding jaws, spaced at .066 in., immersed in carbon tetrachloride and a current of about 100 amperes is sent through the circuit. In an instant the wire ends become plastic, the nickel fuse blows, the current is reduced and the jaws move together to a distance of .033 in. As long as the welding key is depressed the reduced current flows through the joint. Approximately 3 in. of wire on either side of the weld is next annealed in the annealing terminals shown at the top of the wiring diagram, Fig. 9. The resulting joints are very strong and can be drawn through wire reducing dies. Fig. 10 shows the great difference in appearance of .011-in. wires welded in air and welded under carbon tetrachloride. The air welds are brittle, have a crumbling flash and can be broken easily. The carbon tetrachloride welds are smooth and tough,

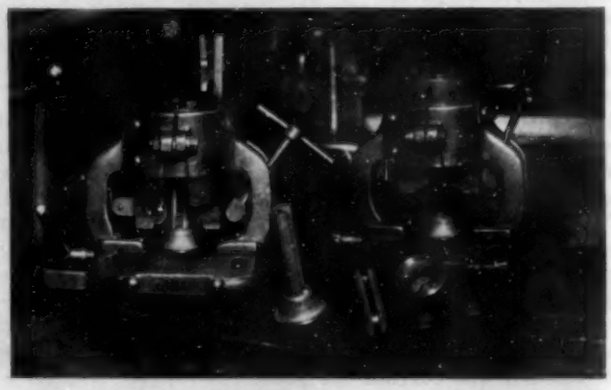


Fig. 11—Fixture for Welding Receiver Magnets

and as strong as any part of the wire. Small nichrome, chromel, perminvar and iron and constantin thermocouple wires can easily be joined by this method.

In welding copper rod a butt welder is used. High current densities, ranging in value from .2 to .4 amperes per circular mil and applied for very short intervals are used for making joints suitable for drawing. For stabilizing the welding current a resistance or reactance ballast is used in the secondary circuit. Rod ends are cut square by means of a circular saw operated by the foot pedal at the left of the machine. This insures good contact and practically eliminates so-called contact resistance and its attending variations. The moving jaw is delicately balanced and is mounted to respond instantly when released. The pressures are selected to insure the proper coordination of jaw move-

ment and current cut-off. Clamps are used to hold the welded joints in a vertical position so that the welding flash may be easily removed. Aluminum for drawing purposes may be joined on similar equipment. However, for this work current densities must be adjusted to about .1 to .25 amperes per circular mil and the jaw pressures tapered off so that the pressure on the joint immediately previous to solidifying is practically zero.

Copper rod and wire welds may also be made under various liquids. Although joints made in water and a solution of hypophosphorus acid have a much cleaner appearance, no increase in strength over those made in air can be detected.

Welders may be used in the manufacture of iron and steel wire, in galvanizing processes and for joining wires and tape used in cable armoring. Iron and low carbon steel wires may be butt-welded, trimmed, redrawn or galvanized and used as part of the finished product. It is very difficult to produce high carbon steel welds which may be substituted for the stock being joined. The completed joint must be carefully heat treated in order to develop characteristics even approaching the original stock.

A punch press type welder is used for welding magnetic iron pole pieces of a telephone receiver to the carbon manganese steel magnet. Fig. 11 shows a close-up of the fixture and parts being welded. The levers shown on the fixture clamp the parts to the electrodes, the tips of the pole pieces projecting through slits in a brass cup. At the completion of the welding cycle the cup is securely fastened so that it acts as a support for the entire magnetic structure of the receiver.

This paper presents some of the resistance welding problems found in a highly specialized industry. The conclusions are all based on work performed at the Hawthorne Plant of the Western Electric Company. It is believed, however, that conditions at this plant are not unusual, but typical and representative of such work anywhere. It is hoped that this discussion may aid in the solution of general resistance welding problems.

The Welded Boiler Drums of the U. S. Navy Scout Cruisers

By J. C. HODGE

✦ Paper to be presented by J. C. Hodge, of the Babcock and Wilcox Company, before the New York annual meeting of the American Welding Society, April, 1931.

LATE last year the Bureau of Engineering accepted fusion arc welded construction for the joints of drums for twenty-four boilers to be used in the three new scout cruisers, Minneapolis, New Orleans and Astoria. The acceptance of the welded joints in these boiler drums was governed by specifications, drawn up by the Bureau, using as a basis the original "Proposed Specifications for Fusion Welding of Drums or Shells of Power Boilers" of the A. S. M. E. Boiler Code Committee, as published in the March, 1930, issue of the Journal of the A.W.S. The Navy Department specifications, however, contain certain desirable features not covered in the original A. S. M. E. proposed code. An outline of these specifications under which the Navy boiler drums are being built was presented in Marine Engineering, December, 1930.

This pioneer step by the Navy Department will be of utmost importance in the final story of the development and adoption of welded construction in all power boilers. It represents the first welded boiler drums and the first welded pressure vessels, built under complete specifications, in which due attention has been given to the welded joints. Regardless of the welding process or manufacturer, drums meeting the Navy specifications will be satisfactory for the service involved.

Briefly, the specifications consist of a testing procedure for the determination of the physical and chemical properties of the weld metal of the joints, and for the determination of the soundness of the welded joints throughout their extent in the drums.

The determination of the physical and chemical properties of the welded joints is made on test plates, which are attached to the ends of the longitudinal joint and welded at the same time and under the same conditions as the joint in the drum. These conditions give the only practical method of securing representative welded test plates. The soundness of the welded joints, that is, freedom from gross defects, is determined by exploration of the entire length of the longitudinal and circumferential joints by the x-ray method. This method of non-destructive testing gives a picture which accurately describes the conditions within the welded joints, and which may be interpreted with facility by anyone with a rudimentary knowledge of simple photography.

The specifications are summarized in Table I.

TABLE I

I. *Stress Relieving.* The completed welded drums together with the test plates were stress relieved at a temperature between 1075 and 1150 deg. F. by heating up slowly and holding at the specified temperature for about 1½ hours and then cooling in a still atmosphere.

II. *Tension Test*
Weld metal to be not less than minimum of tensile range of plate used.

III. *Bend Test*
Minimum per cent elongation of outside fibers—30.0%.

IV. *Charpy Impact Test*—Minimum.....20 ft-lb.

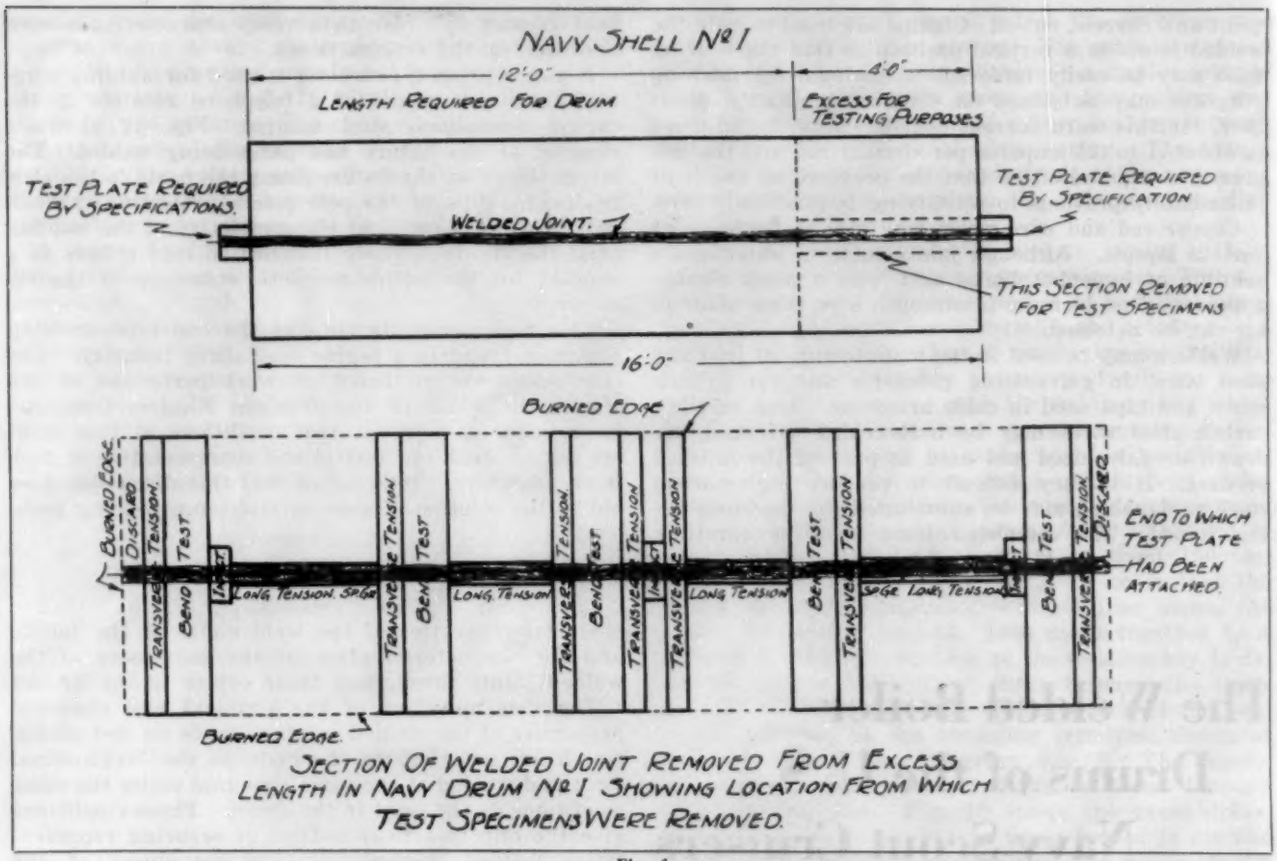
V. *Specific Gravity of Weld Metal*—Minimum.....7.80

VI. *Chemical Analysis*

Manganese	0.30-0.60%
Phosphorus	Not over 0.04%
Sulphur	Not over 0.045%
Carbon	Not over 0.30%
Nitrogen as iron nitride	Not over 0.020%

VII. *Macroscopic and Microscopic Examination*—to be made.

VIII. *X-Ray Examination*
X-Ray examination of the longitudinal and circumferential joints to be in accordance with x-ray examination requirements of the Proposed Speci-



SECTION OF WELDED JOINT REMOVED FROM EXCESS LENGTH IN NAVY DRUM Nº 1 SHOWING LOCATION FROM WHICH TEST SPECIMENS WERE REMOVED.

Fig. 1

fications for Fusion Welding of Unfired Pressure Vessels; published in Journal A.W.S., January, 1931.

IX. *Hydrostatic Test*

Drum to be subjected to a hydrostatic test pressure equal to twice the working pressure of the drum.

The three scout cruisers, Minneapolis, New Orleans and Astoria, require twenty-four boilers. In addition orders have been received for eight boilers for a fourth scout cruiser and for six boilers for the aircraft carrier CV4. The boilers are of the Sectional Express type, each boiler for the cruisers having sixteen sectional headers and for the aircraft carrier twelve sectional headers.

The working pressure of the boilers is 320 lb./sq. in. The steam drums, which have the welded joints, are of the following dimensions, 47⅜ in. I.D. x 13 ft. 9⅜ in. overall length x 1 7/32 in. thick. The plate used in Class A, Marine Boiler Plate, Navy Specifications No. 48P2d with the following properties:

Tensile Strength	60-70,000 lb./sq. in.
Yield Point	½ Tensile Strength
Elongation in 8 in. min.	1,500,000
	Tensile Strength
Phosphorus	0.04% max.
Sulphur	0.04% max.

To show the quality of the welded joints in the drums themselves, when a drum is welded under the

TABLE II—TENSION TESTS—Rectangular, Transverse to Welded Joint
Weld at Center of Specimen

Specimen Number	2102-1	2102-2	2102-3	2102-4	2102-5	2102-6	2102-7
Dimensions	.505 x .978	.486 x .980	.502 x .797	.498 x .978	.497 x .978	.494 x .980	.501 x .976
Tensile Strength—Plate	.....	65,600	63,100	.....	65,100	.....	65,300
Tensile Strength—Weld	65.800	.....	.....	65,950	.....	65,750	.....
Yield Point—Plate	42,500	41,000	40,700	40,700	40,200	40,800	40,700
Yield Point—Weld	48,200	49,750	49,600	48,200	49,400	49,050	50,200
Elong. in 1" Across Weld (When Weld Fractured)	46.0%	.....	.....	48.0%	.....	48.0%	.....
Elong. in 1" Across Fracture in Plate	.....	55.0%	58.0%	.....	60.0%	.....	57.0%
Reduction of Area at Weld (When Weld Fractured)	48.8%	.....	.....	55.8%	.....	55.8%	.....
Reduction of Area at Fracture in Plate	.....	52.3%	53.0%	.....	55.2%	.....	54.0%
Fracture	In weld	In Pl. 4" from center line of weld	In Pl. 3½" from center line of weld	In weld	In Pl. 2" from center line of weld	In weld	In Pl. ¾" from center line of weld

foregoing specifications, one of the steam drums was constructed of plate of extra length to give a shell from which the excess length of the longitudinal joint could be removed for testing purposes, as shown in Fig. No. 1.

From this excess length, tension specimens both transverse and longitudinal, bend test specimens, impact specimens, specific gravity specimens and speci-

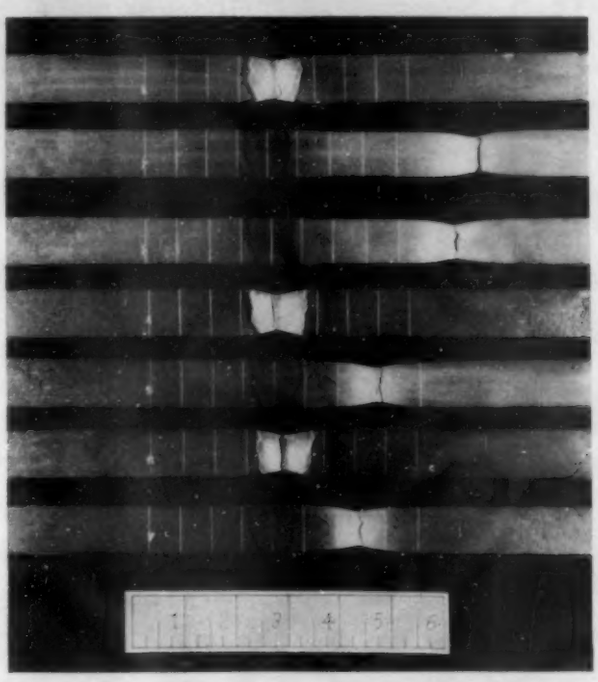


Fig. 2—Transverse Tension Specimens on Marine Plate (60,000-70,000 lb./sq. in. Tensile Range). Fractures—4 in Plate, 3 in Weld

mens for macroscopic and microscopic examination were removed.

Transverse Tension Specimens

Fig. No. 2 shows seven transverse tension specimens, the test data of which are given in Table II.

The remarkable uniformity of the values obtained should be noted. The average physical properties of both the plate and the weld metal as obtained from the above data are given in Table III.

TABLE III

	Plate	Weld Metal
Ultimate Strength, lb./sq. in.....	64,775	65,830
Yield Point, lb./sq. in.....	40,940	49,200
Reduction of Area at Fracture, %...	53.6	53.5
Elongation in 1" Across Fracture, %	57.5	47.3

The physical properties of the two steels comprising the welded joint are remarkably similar. This is clearly indicated by four specimens failing in the plate material and three in the weld metal. This striking homogeneity is further illustrated in the photograph of the fractured specimens, which show a uniform elongation across the welded joint in those specimens where failure occurred in the plate.

Longitudinal All-Weld Metal Tension Specimens

Four longitudinal all-weld metal specimens gave the following data:

TABLE IV

	2102-1	2102-2	2102-3	2102-4	Average
Proportional Limit	45,500	45,250	50,000	42,500	45,800
Yield Point 5% Elong.	47,750	48,500	49,500	48,500	48,560
Yield Point (Drop)	47,500	47,300	52,250	47,500	48,640
Tensile Strength	61,750	62,000	63,250	62,300	62,320
Elongation in 2"	52.5%	32.5%	32.0%	32.0%	32.2%
Reduction in Area	60.6%	56.2%	58.3%	58.3%	58.4%
	Full cup	2/3 cup	3/5 cup	½ cup	

This data are conveniently summarized in Table V, which again indicates that very little variation exists in the physical properties of specimens removed from different portions of the welded joint.

TABLE V—All-Weld Metal Specimens

	Maximum	Minimum	Average
Proportional Limit, lb./sq. in.	50,000	42,500	45,800
Yield Point, lb./sq. in.....	49,500	47,750	48,560
Ultimate Strength, lb./sq. in..	63,250	61,750	62,320
Elongation in 2".....	32.5%	32.0%	32.2%
Reduction in Area.....	60.6%	56.2%	58.4%

Bend Test Specimens

Five bend test specimens, bent to the positions shown in Fig. 3, gave the following data:

TABLE VI—Bend Tests

Specimen Number ...	2102-1	2102-2	2102-3	2102-4	2102-5
Angle of Bend.....	190°	180°	180°	180°	180°
Inside Radius	0.5"	0.75"	0.63"	0.63"	0.75"
Per cent Elongation of outside fibers in 1" across weld.....	62.5	47.5	52.5	52.5	52.5

All specimens bent without fracture.

Impact Specimens

Impact specimens obtained from top and bottom zones of welded joint gave the following values:

TABLE VII—Impact Tests

Specimen No.	Location	Ft-Lbs.
2103–1	Top	29.5
	Bottom	27.0
2103–2	Top	26.0
	Bottom	25.5
2103–3	Top	27.5
	Bottom	23.0
	Average	26.4

Specific Gravity

Two specific gravity specimens gave values of 7.80 and 7.81.

A review of the properties obtained on the seven transverse tension specimens, the four longitudinal tension specimens, the five bend test specimens, the six impact specimens, and the two specific gravity specimens, taken at different locations along the longitudinal joint, clearly indicates the uniformity of the weld metal.

Chemical Analysis

The Navy Specifications call for chemical analysis of the weld metal. Reasons for the inclusion of a specification governing the chemistry of weld metal,

have already been given. (See paper presented before Western Metal Congress, American Welding Society, February, 1931.)* It was then shown that the resistance of a weld metal to corrosion could be correlated with the nitrogen content of a weld metal. To date the correlation of nitrogen content with the physical properties of weld metal has not been published, as far as the writer is aware.

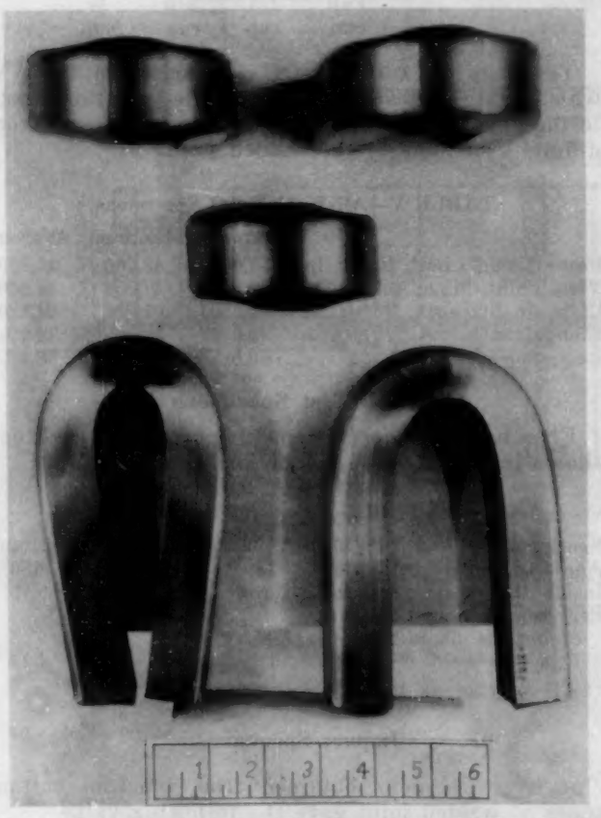


Fig. 3—Bend Test Specimen. Elongation of Outside Fibers in 1" Across Weld: Min., 47.5%; Max., 62.5%; Ave., 53.5%

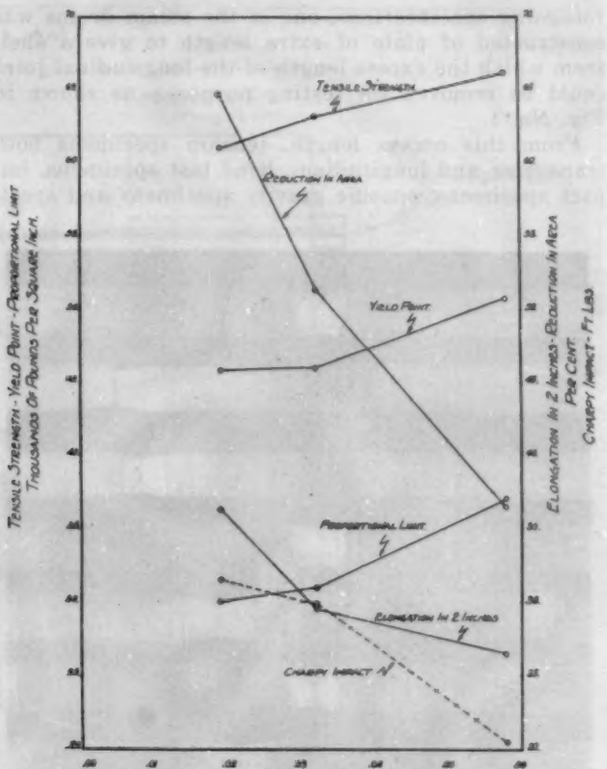
The following investigation was made to determine the effect of different degrees of protection from atmospheric contamination, all other factors being held constant, upon the properties of weld metal. Three welds were made, the atmospheric conditions surrounding the arc being so regulated as to produce weld metals with nitrogen contents of 0.058 per cent, 0.032 per cent, and 0.019 per cent. Tensile and impact specimens were obtained from the three welds. The relationship existing between the physical properties and the nitrogen contents of the three welds is shown diagrammatically in Fig. 4.

These results show that, all other factors remaining the same, increasing nitrogen content (or increasing atmospheric contamination) causes:

(1) An increase in the proportional limit, the yield point, and the tensile strength of the weld metal, and,
(2) A decrease in the ductility criterions, elongation and reduction of area of the weld metal, and,
(3) A decrease in the resistance to impact of the weld metal.

This investigation has been very briefly reported above. A more thorough discussion of the effect of nitrogen on weld metal will be later published.

*To be published in May, 1931, issue Journal of the A. W. S.


Tensile Strength
Reduction in Area
Yield Point
Proportional Limit
Elongation in 2 Inches
Charpy Impact
Tensile Strength - Yield Point - Proportional Limit - Thousands of Pounds Per Square Inch.
Elongation in 2 Inches - Reduction in Area - Per Cent. Charpy Impact - Ft Lbs
Nitrogen - Per Cent.

The Relation Between Nitrogen Content And Physical Properties Obtained On .505 Inch Dia. x 2 Inch Ga. Length All Weld Metal Tension Test Specimens. Barberton Weld Strain Relieved At 1200°F

Fig. 4

X-Ray Examination

All of the main joints in these navy drums are being x-rayed. Our experience indicates that x-ray examination of welded joints in boiler drums and other

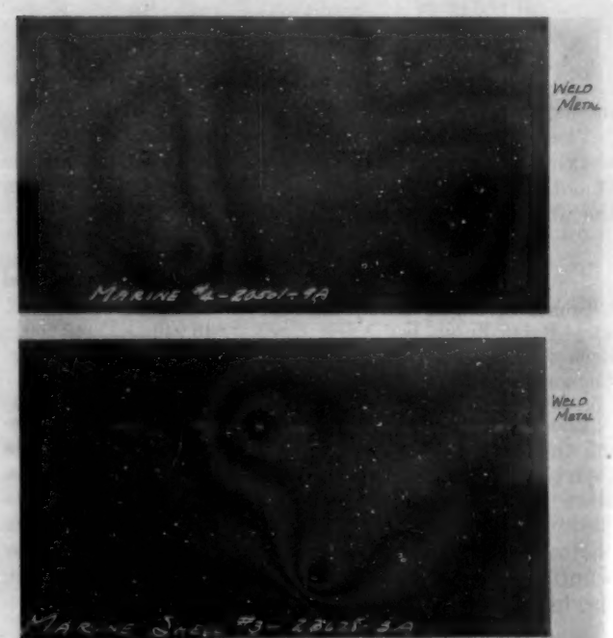


Fig. 5 (Upper)—Excellent X-Ray Print Typical of 23 Acceptable Welded Joints

Fig. 6 (Lower)—Non-acceptable X-Ray Print of Defective Weld in One Joint. Entire Seam Machined Out and Rewelded

similar high temperature high pressure vessels is absolutely necessary in order to secure the best work and the greatest safety.

Taking the twenty-four longitudinal joints of the steam drums, twenty-three of them complied with the specification without re-welding and the x-rays were of the type shown in Fig. 5. One of the longitudinal joints, however, showed on x-ray examination zones containing defects of type represented by Fig. 6. This x-ray did not comply with the specifications and the entire longitudinal seam was machined out and the joint re-welded. X-ray examination of this second weld in the longitudinal joint complied with the specifications. If the x-ray test had not been applied to the twenty-four drums, one of the drums would have gone into service with a potentially dangerous defect in its longitudinal joint. The above experience stresses the importance of x-ray examination in a specification for welded pressure vessels.

Available data show the necessity for x-ray examination of welded joints in pressure vessels regardless of the particular welding process used or the manufacturer of the vessel. X-ray examination of seams welded by several other commercial welding processes has been made and in the majority of cases dangerous defects were found.

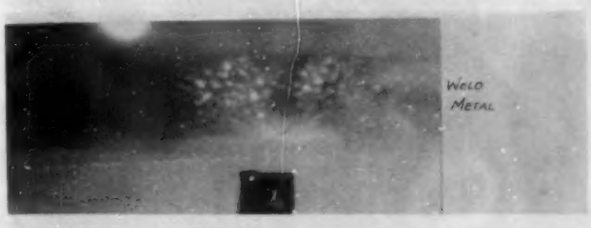


Fig. 7—X-Ray of Welded Joint Submitted for Examination By Another Manufacturer

Fig. 7-A. Macrograph of Section Through Weld, X-Ray of Which Is Given in Fig. 7

Fig. 8—X-Ray Print of Welded Joint Without Removal of Excess Weld. Weld Plainly Seen Due to Greater Thickness Than Plate. No Defects

Fig. 9—As Above, but Small Defect Present. Defect Represented by Small White Spot at Bottom of Dark Zone. Defect Not Large Enough to Cause Rejection of Joint

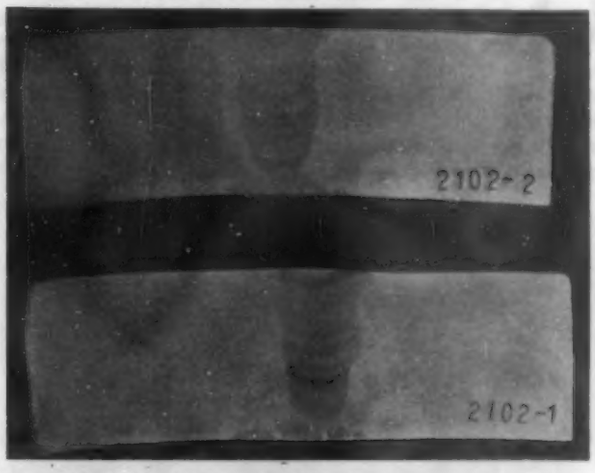


Fig. 10—Macrographs of Two Typical Sections Through Marine Joint

As an example, Fig. 7 is presented, showing a welded joint submitted to us for examination by another manufacturer. Excessive porosity is indicated, and near the end of the x-ray the thin straight white line along the center of the joint indicates the presence of incomplete fusion (a very dangerous type of defect). X-ray examination of other processes revealed defects of an even more serious nature. A macrograph of the weld in Fig. 7 is shown in Fig. 7A.

Figs. 8 and 9 show x-ray prints of welded joints without removal of the excess material. Fig. 10 illustrates macrographs of typical cross sections of the welded joints.

Our experience with the use of x-rays for examining the welded joints convinces us that this or some other means of permanently recording the condition of the welds should form a part of any specification for the best type of fusion welding. This, combined with the other test requirements, insures a safe and reliable construction.

Some Examples of Welding in Structural Steelwork

By D. C. TENNANT

✦ This paper is to be presented at the Annual Meeting of the A. W. S., by D. C. Tennant, Structural Engineer of the Dominion Bridge Co. Limited.

ONE of the most impressive aspects of fusion welding and especially electric arc welding is the ever-increasing use made of it in structural steel fabricating shops. Our company, which can probably be taken as typical of most Canadian fabricating companies in this respect, does not deliberately set out to sponsor either welding in general or any particular type of it; but it does constantly try to

Fig. 1—Caustic Liquor Tank

find means of attaining good results by new and more economical means and also better results at a justifiable increase in expense. One of our aims is to introduce new methods wherever it pays us—and not otherwise. Gas welding and electric arc welding—particularly the latter—have been in vogue in our shops now for many years, our welders have been carefully and systematically trained and tested, and we strive to use welding wherever it passes this acid test—that is where it pays.

The plate and tank shop early recognized the advantages of welding, so that now a great deal of the lighter work is done entirely by welding. In the heavier work, such as penstocks, where plates up to 1¾ in. thick occur, welding is used sometimes instead of caulking, the strength being supplied by the riveting and the watertightness by the welding. Welding replaces riveting on pontoons, caustic liquor tanks, gasoline tanks, water tanks, evaporators and many other watertight vessels. One of the cases where welding has eliminated riveting is in the long pipe line for the suction dredge which has been working on the new St. Lawrence River Canal at Beauharnois, Que. Another striking example is in the simplifying of Y connections in penstocks due to welding.

Certain details in connection with mechanical work lend themselves to welding. Shaft brackets are made

Fig. 2—Welded Wye

by welding together bent plates and then machining, thereby effectively replacing cast iron or cast steel shaft brackets. The end trucks for cranes are also built up by bending, welding and machining structural plates, thus making a strong frame free from the sort of material flaws that might be hidden in castings. Our company has in fact built a crane of all welded construction, which has been giving very satisfactory service for three or four years. Then welding has also been used to advantage on hydraulic gates. The Canadian climate introduces difficulties in the freezing up

Fig. 3—Shaft Bracket

of some of these gates. One of the must useful agencies in overcoming these difficulties is the heating duct built in the bedded parts of the gate and paralleling the roller path. These ducts are also best built by welded construction, as this ensures airtightness. We have been able also to improve and cheapen trash racks by substituting angle separators welded between the rack bars instead of cast spools bolted by long bolts.

The quantity of structural steel needed in Canada is,

of course, very much less than in the United States and it is probably due to this fact that some of the Canadian shops handle a greater variety of structures than is common to most American plants. Our Montreal shop, in addition to the plate and mechanical work already mentioned, turns out steel for bridges and buildings of all sorts, coal towers, conveyors, outdoor substations, transmission towers, head frames, elevators, fences, draft arms and all the class of work

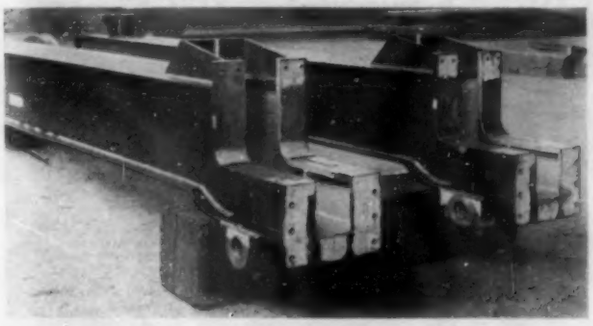


Fig. 4—Crane End Trucks

known as "chicken-feed"; this whole list being referred to as structural work. It is the development of welding in this field that most invites the attention of the structural man. Existing shops are already equipped for riveting all this work, therefore we might expect the shop man to be averse to changing his methods. On the contrary, the intelligent introduction of welding for selected purposes into structural shops seems to have almost entirely overcome this aversion, if indeed it ever existed. A few almost random examples of the use of welding in our structural shops in Montreal and Toronto have been chosen and are shown in Figs. 1 to 18, inclusive. Fig. 19 lists these examples and shows that almost invariably the substitution of welding for riveting results in a saving in the weight of the steelwork.

Fig. 6 shows a fence post made of a tee burned from

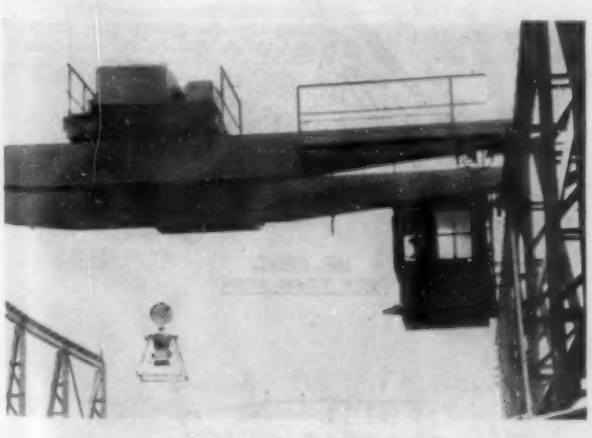


Fig. 5—Welded Crane

an 8-in. beam, the stem of the tee being deep at the sidewalk level where the bending moment is great and tapering to a small dimension at the top where there is no moment. The cutting of the tee is so arranged as to entirely eliminate any waste. The tee post has a small plate welded on as cap and the base is welded to the outer end of a horizontal steel beam which is in turn bolted to the wooden floor beam of the bridge. This was an old wooden bridge of quite a length and it was decided to install new fence posts. As there was considerable duplication, the saving resulting from the welding proved very advantageous. Fig. 7 is another fence post used on a new steel highway bridge. No riveting was used and the number of posts alike justified the making of a special jig that accurately determined the position of the cap, base, and lugs, and held these in position during welding. On the same highway bridge the through main longitudinal girders came between the sidewalk and the roadway. The specifications called for a certain side thrust applied at the top flange of these girders to be resisted in bending by the stiffeners occurring at each floor beam connection. Thus these stiffeners had to be reinforced as shown in Fig. 8 by adding smaller angles on the outside edges of the main stiffeners. Welding was used at the bot-

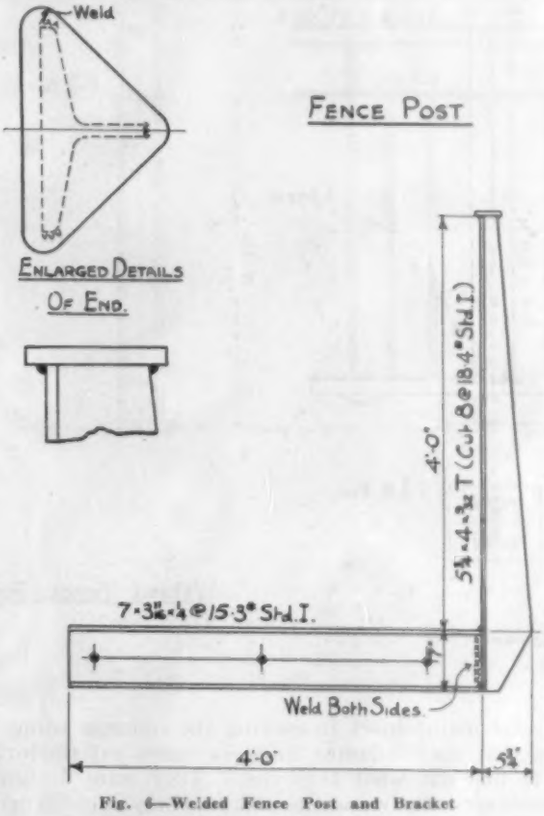


Fig. 6—Welded Fence Post and Bracket

toms of the stiffeners to resist the reverse side thrust and also for fastening in place on the girder webs the lip plates that followed the vertical curve of the concrete slab on both roadway and sidewalk; these lip plates being, therefore, not parallel to the girder flanges. On some of the heavier pier members for both railway and highway bridges, thick plates have been used, welded together to resemble the horizontal and vertical ribs of the ordinary steel casting. Fig. 9 is one of these. It was machined on the bottom after welding and also bored. The vertical ribs were edge planed to ensure bearing. Figs. 10 and 11 are welded diaphragms at hip joints on a bridge pony truss and a log stacker frame, respectively. In both cases there occurs at the joint a component outward from the hip joint and this is resisted by a third member connecting to a gusset plate at the joint. But the gusset plate is connected to only one leg of the chord angle; the problem is to take care of that part of the outward com-

ponent that arises from the stresses in the outstanding legs. This is very simply done by the welded diaphragm, whereas a riveted detail would be cumbersome and rather ineffective.

About four years ago, we decided to try some completely welded crane columns and we built three of them, which we are illustrating in Fig. 12. Pictures of these have appeared more than once in various publications. We were young in welding experience

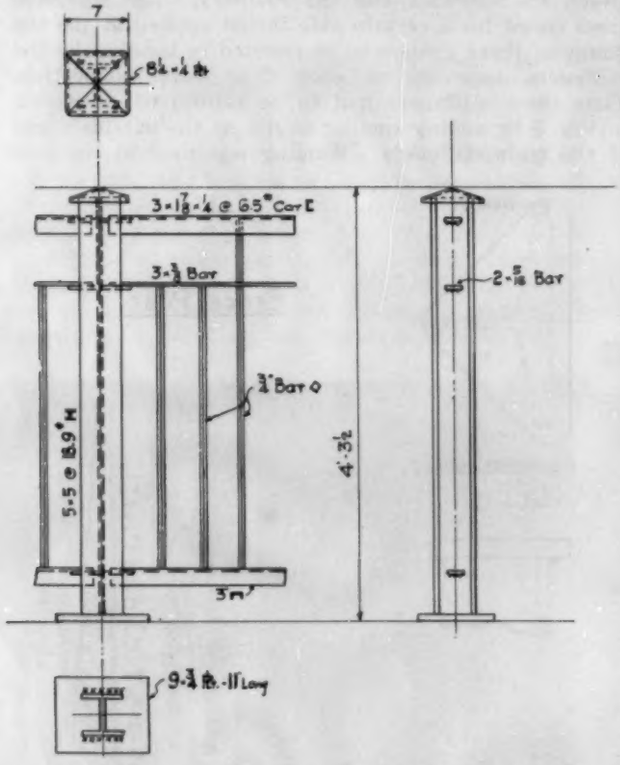


Fig. 7

then, our main object in making the columns being to prove that such columns could be made satisfactorily and to find out what they cost. They were designed ultra-conservatively and the cost was only slightly more than that of riveted crane columns that occurred in the same building. It is quite likely that if designed and fabricated now a distinct saving would be shown. Another example, Fig. 13, shows the use of welding on crane runways beams. These beams had stiffening channels with horizontal webs inverted on the top flanges and these channels were welded to the beams, thus avoiding the use of countersunk rivets or alternatively short fillers of sufficient thickness to raise the bottom of the crane rail above the rivet heads that protrude above the channel web. The Canadian General Electric Co. have at various times recently made extensions to their plant at Peterboro, using all welded roof trusses. Fig. 14 shows some of the saw tooth trusses fabricated for this plant. These trusses were welded in the shop before shipment. The Canadian Bridge Co. of Walkerville also supplied welded roof trusses for this plant, but they were much larger and the welding was done at the site, the trusses being assembled and clamped together on the ground before welding. Fig. 15 illustrates a very light truss used to support a canvas roof at a mountain resort. Welding was used, resulting in a lighter and more ornamental frame. Some of the members were composed of gas pipe. Fig. 16 also shows a light structure—a gantry frame for supporting electric wiring and apparatus. Similarly in Fig. 17 the truss of a large

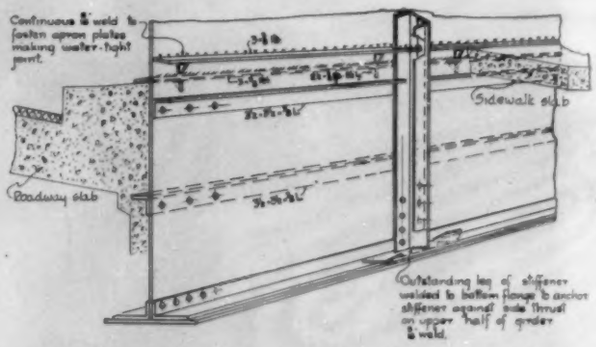

Continuous ⅜" weld to fasten apron plates making water-tight joint.
Sidewalk slab
Roadway slab
Outstanding leg of stiffener welded to bottom flange to anchor stiffener against side thrust on upper half of girder ⅜" weld.

Fig. 8—Welded Lip Plate and Stiffener on Highway Girder

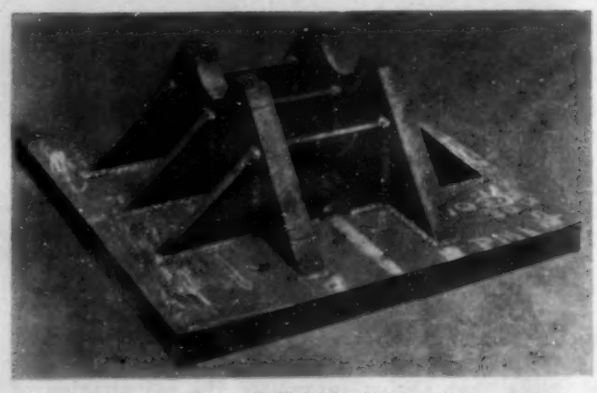
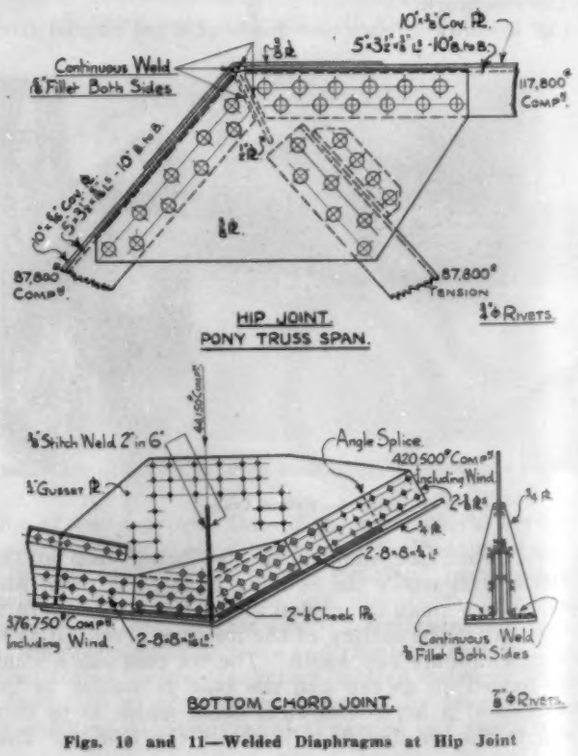


Fig. 9—Welded Pier Member



Figs. 10 and 11—Welded Diaphragms at Hip Joint

jib crane was welded with only sufficient holes inserted to facilitate its being put together at the site. Finally, Fig. 18 illustrates a welded canopy for a service station as developed by our Toronto designers. This frame has proved very pleasing and effective so that it is looked on as standard construction.

It will be observed from these examples that in some cases whole structures are welded, while in others it is used only in certain places. Where any combination

Fig. 12—Welded Crane Columns

of riveting and welding has occurred we have tried as far as possible to have important stresses or strains resisted all by welding or all by riveting. We do not know just how the distribution of stress would work out in a joint partly welded and partly riveted. By referring to Fig. 18, it will be noted that in Examples 8, 10 and 11 the saving in weight shown refers not to the whole member, but only to the welded details. Similarly, Fig. 13 is only partially welded. Fig. 15 is scarcely typical, because the welded and also the riveted structure is extremely light and probably could have been made considerably lighter. It is apparent, however, from the balance of the examples that they represent a legitimate saving of anything up to 25 per cent in weight. This saving in weight is not necessarily reflected in like proportion in the costs. The saving in cost, if any, very usually depends on the extent to which special methods, such as jigs, are effectively applied and this is always dependent on the amount of study given and also on the amount of duplication of pieces.

We are all familiar with the practice in reinforced concrete design of counting on the concrete to resist compression while the steel reinforcing bars resist tension. Nevertheless, when structural steel is encased in concrete it is commonly assumed that the steel takes all stresses, both tension and compression, while the concrete does nothing. This assumption evidently allocates to the steel more stress than it will ever actually get and has resulted in comparisons between the cost of reinforced concrete construction and steel construction being more favorable to the former than is quite justified. Such comparisons in Canada favor reinforced concrete, even more than they do in the United States, because concrete materials are about the same price in both countries or perhaps cheaper in Canada, while steel is more expensive there than in the United States. Recently in Montreal there has been erected the "Architects Building," a seventeen-story structure, two hundred and twelve feet high and covering an area at the base of about seventy feet by one hundred. This was to have been built of reinforced concrete construction throughout, but **Mr. Kane**, one of our engineers, conceived the idea of reducing the weight of the steel design by replacing all the heavier steel beams by light welded trusses which would in turn carry the usual "Truscon" or "Massillon Bar" open steel joists of the floors. Fig. 20 shows the construction. These welded trusses are encased in concrete. The top chord of the truss is composed of two angles strong enough to take the top chord stress due to the load during construction while the concrete is being poured and before it sets. Thus no shoring is necessary for the forms. The bottom chord of the truss is composed of two heavier angles capable of taking all the tension that will occur when the full dead and live load is applied. The diagonals are of

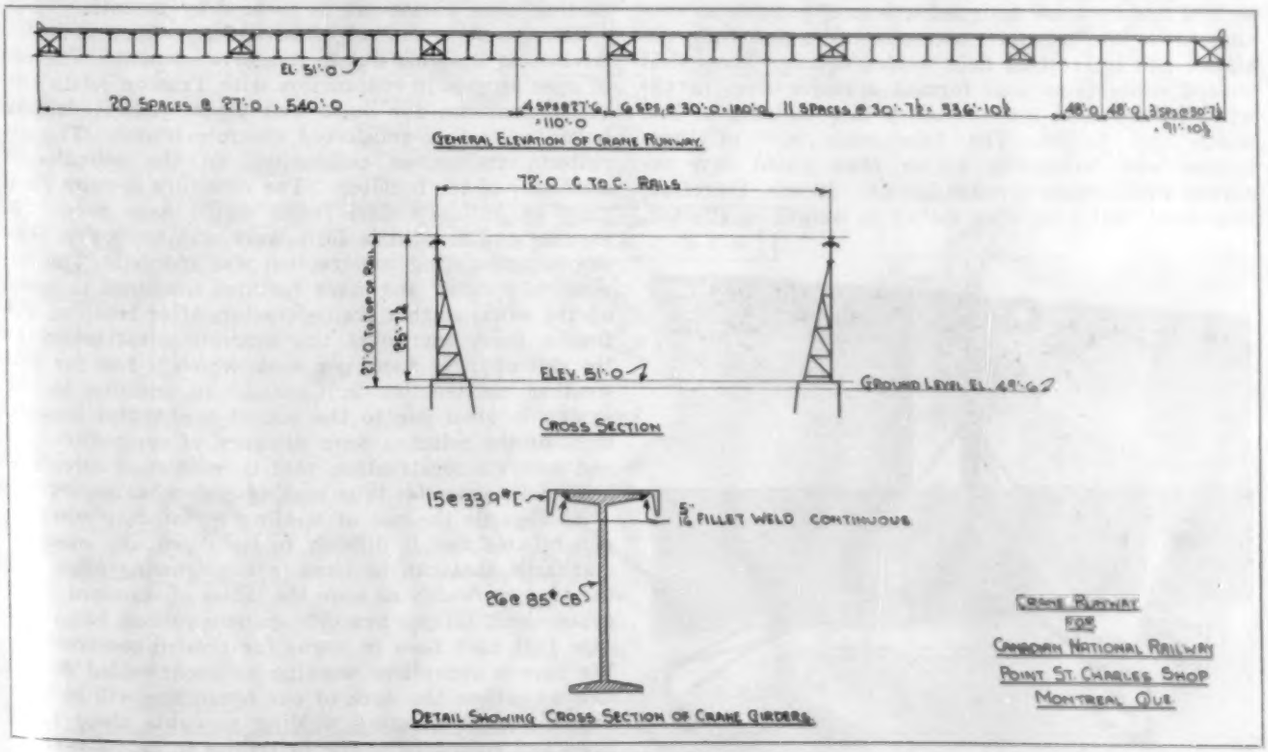


Fig. 13—Welded Crane Runway Beams

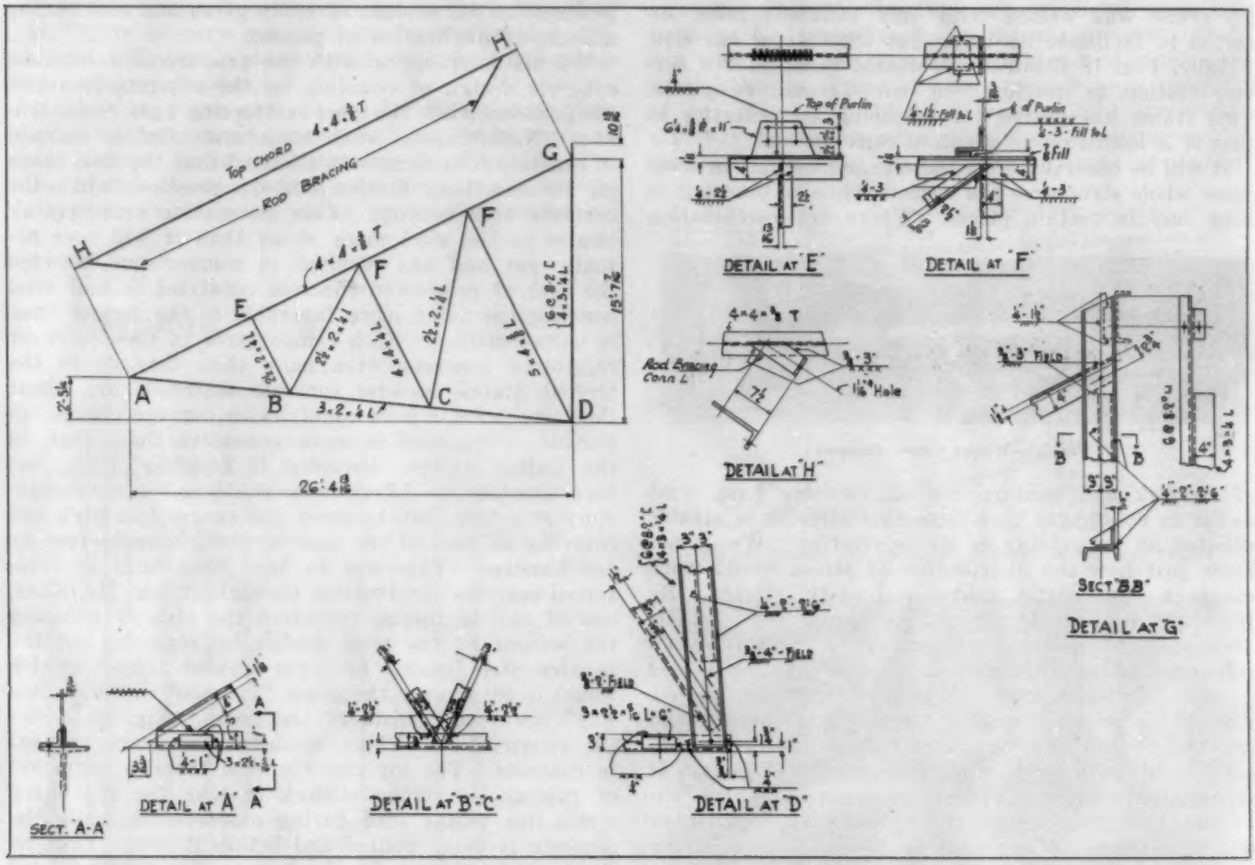


Fig. 14—Saw Tooth Truss for Canadian G. E. Co., Peterboro

angles or flats sufficient to take the shearing stresses and so arranged that they will intersect the top chord at the points of support of the "Truscon" joists. These welded trusses were designed wherever possible as continuous at the columns, necessitating a carefully designed and interesting field welded detail. These field welded connections also formed a major item in the wind bracing that was necessary in a building of this width and height. The fabrication cost of these trusses was necessarily higher than would have occurred with ordinary rolled beams. It was, therefore, important that a striking saving in weight be effected.

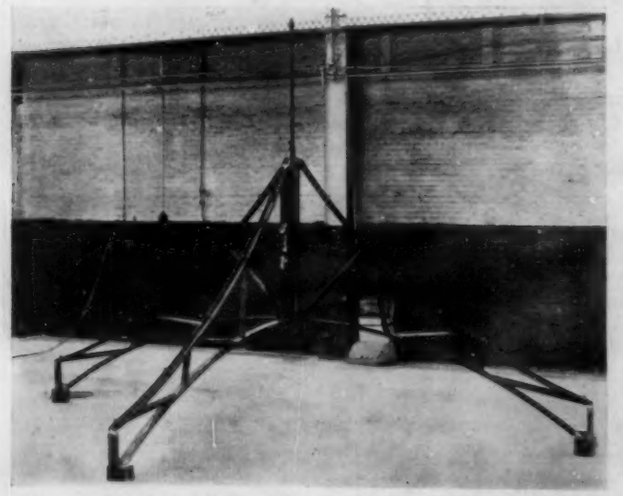


Fig. 15—Truss to Support Canvas Roof

This was readily accomplished by the adoption of welding for the trusses. Riveted construction could not have attained the desired end. This construction, including some variations, is covered by patents.

There were a number of advantages apparent in the Architects Building due to this arrangement. The use of open trusses in conjunction with Truscon joists provided clearance for ducts and pipes without drilling holes in steel or reinforced concrete beams. The architects themselves commented on the sound-proof character of the building. The structure is more rigid than an ordinary steel frame would have been. No shoring and very little form work was necessary, thus fire hazard during construction was reduced. The absence of shoring and other features combined to speed up the work, so that the contractor, after reaching the fourth floor, completed the concrete construction at the rate of three floors per week, which is fast for cold weather construction in Canada. In addition to the saving in steel due to the use of the welded trusses, most of the columns were designed of composite steel and concrete construction, that is, with steel cores embedded in concrete, thus making a further saving.

As regards the use of welding in building work in general, we find it difficult to lay down any rules or standards that can be used in the drawing office and the shop as readily as were the tables of standard beam connections, column brackets, column splices, bases and caps that have been in vogue for riveted construction. We have a committee working on such welded details and we believe the work of our committee will be very valuable in stimulating welding thoughts along right lines and emphasizing the principles to be followed in the various details. Yet we think each welded struc-

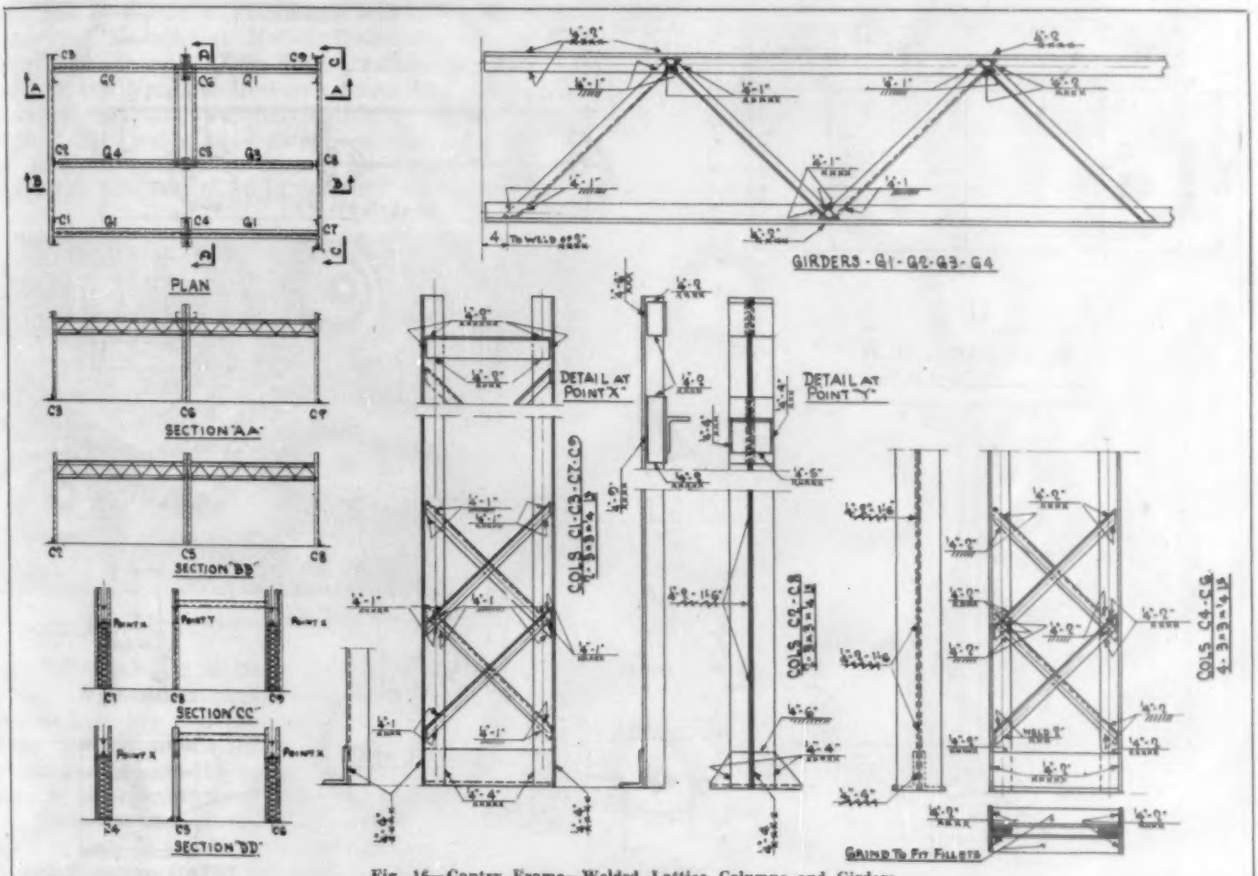


Fig. 16—Gantry Frame—Welded Lattice Columns and Girders

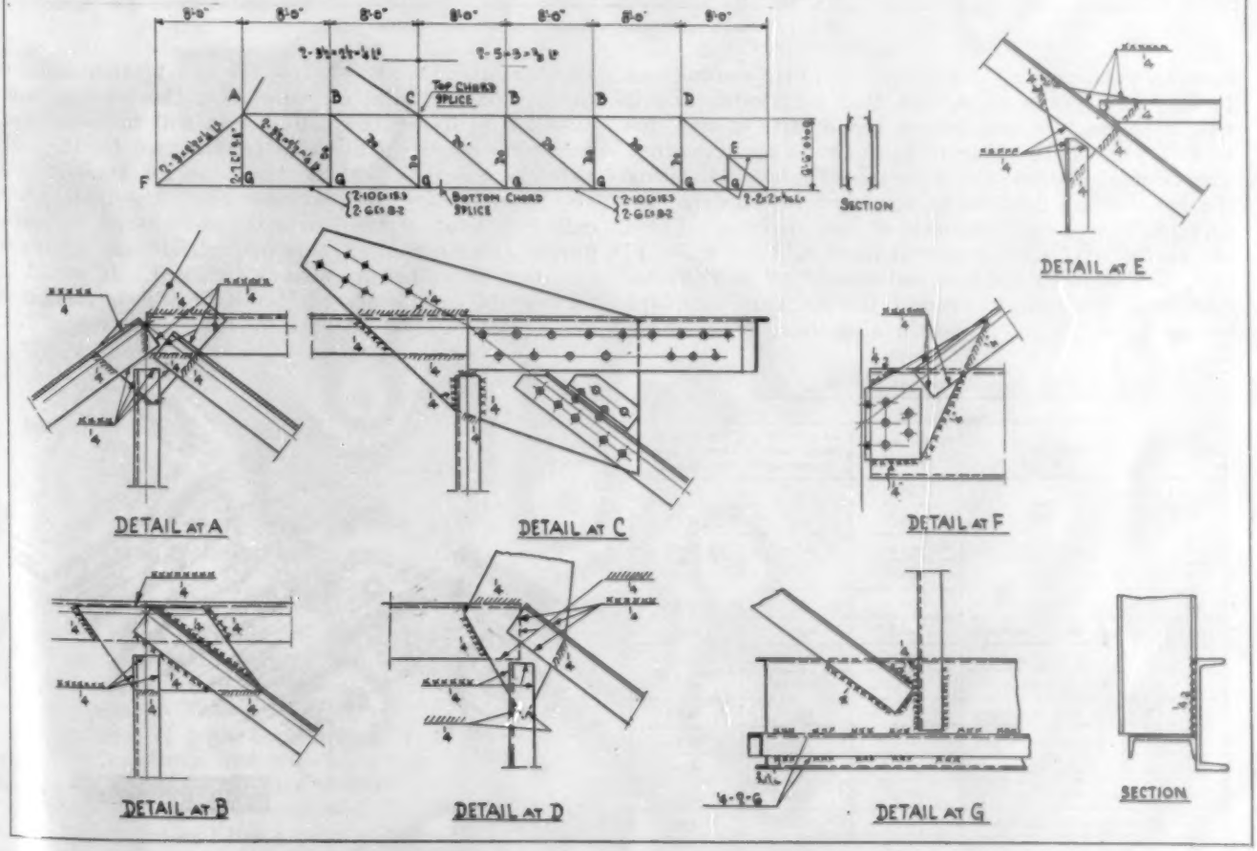


Fig. 17—Welded Connections for Jib Crane Truss

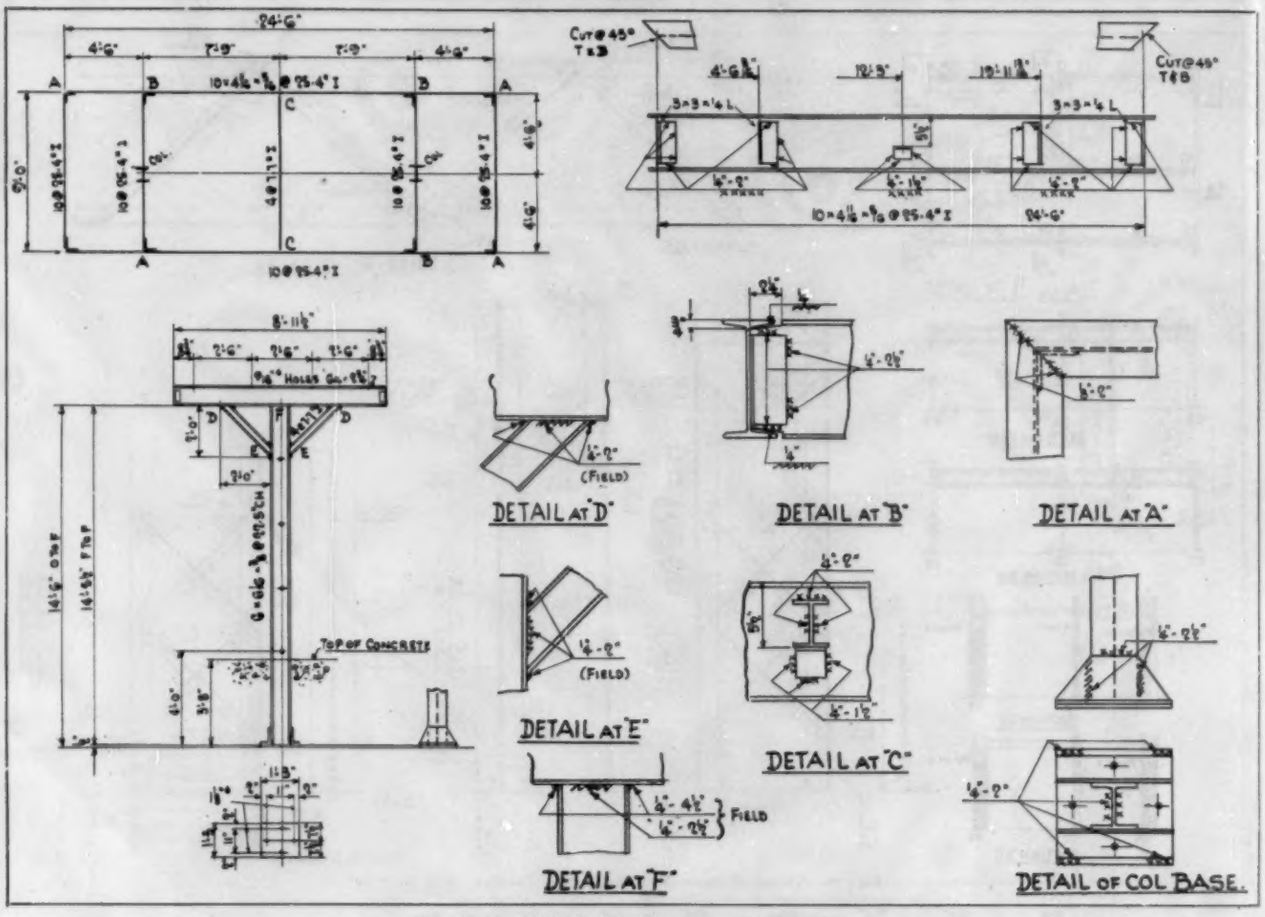


Fig. 18—Standard Welded Canopy for Service Station

ture as it comes up deserves individual engineering to suit any special conditions that may exist, and it will be some time yet before the details of any one welded job will be likely to conform to set standards. The General Electric Co. have issued tables indicating the longitudinal fillet welds necessary to properly connect angles, tees and channels of various sizes. These are useful. We have prepared three tables—"P," "Q" and "R"—showing the size and amount of longitudinal fillet weld required to connect the ordinary standard beams up to 24 in. in depth, also the corresponding Bethlehem and C. B. shapes, for full tension value of the sections and also for developing the bending value by fillet welds on the flanges. It will be noted that somewhat smaller fillet welds are specified for the light Bethlehem beams, because the edges of their flanges are thinner than the other sections. The tables show only two lines of fillet weld on each flange. This is purely diagrammatic and is not intended as a suggestion that two lines are always sufficient. It would, in fact, in the case of the heavier beams, be important to arrange for several lines rather than only two, so that

TABLE SHOWING SAVING IN WEIGHT DUE TO WELDING

Fig. No.	Description	Weight with Welding	Alternative Weight with Rivetting	Percentage Weight saved by Welding
6	Fence Post	45#	60#	25.0%
7	Fence Post	109#	119#	8.4%
8	Highway Bridge Girders	8.0# per lineal foot	18.1# per lineal foot	55.9%
9	Bridge Piers Members	1490#	Casting 1850#	19.5%
10	Bridge Hip Joint Diaphragm	13#	38#	65.8%
11	Log Stacker Joint Diaphragm	44#	147#	70.2%
12	Mill Building Columns	3740#	3650#	—
13	Crane Runway Girders	350210#	352750#	0.7%
14	Saw Tooth Roof Truss	1000#	1200#	16.7%
15	Truss to Support Canvas Roof	115#	218#	47.3%
16	Outdoor Electric Gantry	16420#	17850#	8.0%
17	Jib Crane Truss	3250#	3690#	11.9%
18	Canopy for Service Station	3185#	3350#	4.9%

Fig. 19

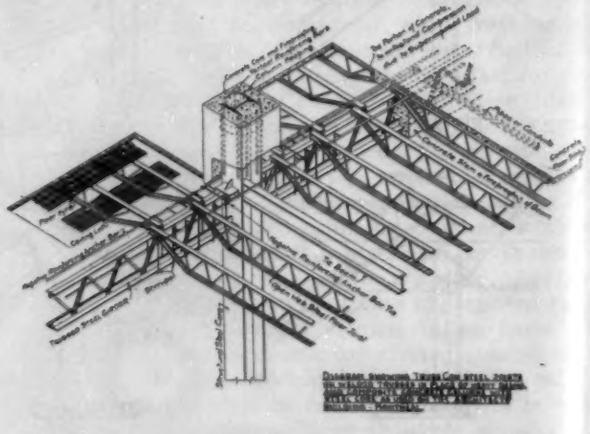


Fig. 20—Patented Welded Truss for Buildings

each line would be of reasonable length. Experiments conducted recently at McGill University by the late Dean MacKay and A. M. Bain are published in a bulletin of the National Research Council of Canada and indicate regarding the distribution of stress in longitudinal fillet welds, used as splices, that in a weld 7½ in. long the maximum stress per lineal inch is 1.7 times the average, in 15 in. long 2.2 times, in 22½ in.

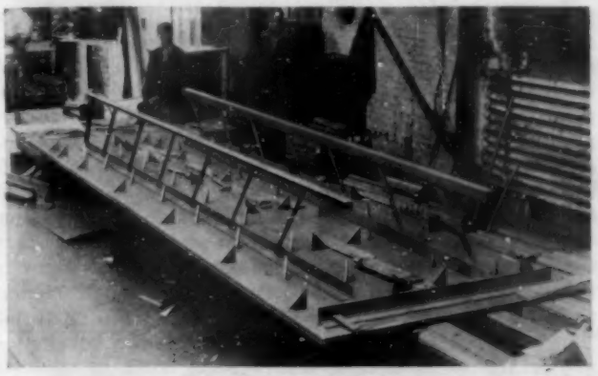


Fig. 21—Fabrication of Welded Truss by Jigs

long 2.6 times and in 30 in. long 3.0 times the average stress. The experiments were made with two flats welded together and the entire stress was transferred from one flat to the other. The unequal distribution of stress is due to the variation in the distortion of the flats at different places. Similar variations in stress are found in the rivets of a riveted joint where the joint is long in the direction of the line of stress. The McGill experiments do not seem to argue against fairly long welds on connection angles carrying shear from

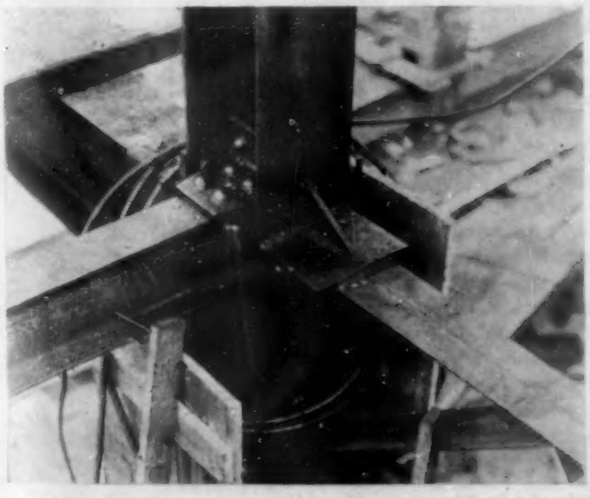
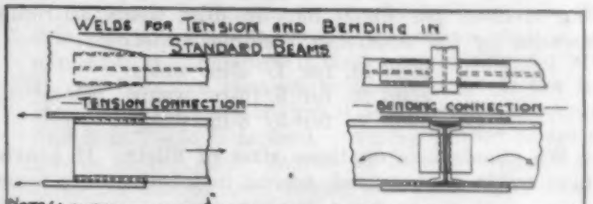


Fig. 22—Erection of Welded Trusses

the web of a beam into the web of a supporting girder or column, because in this case the stress is transferred out of the connection angle as quickly as it enters and no great variation in distortion seems possible. Referring again to Tables "P," "Q" and "R," it should be noted that if both flanges of a beam are rigidly welded to a column and the column is held from deflecting as would be the case with a similar beam connecting to the opposite face, then the beam acts as a continuous beam and has a maximum bending moment at the column which must be developed by the welded



NOTE (a) IN DETAILING, SPECIFY 1 MORE ON EACH LINE OF WELD THAN IS CALLED FOR IN TABLE
(b) IF VERTICAL DISTANCE BETWEEN WELDS FOR BENDING BE LESS THAN DEPTH OF BEAM, LENGTHS OF WELDS SHOULD BE INCREASED ACCORDINGLY

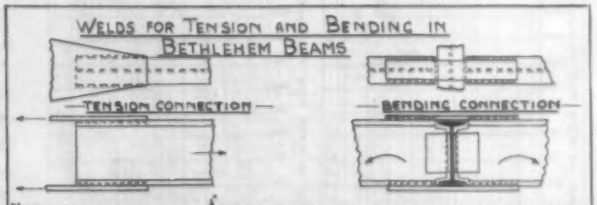
BEAM.	TENSION				BENDING			
	AREA.	TENSILE STRENGTH AT 18000 #/□"	SUITABLE SIZE OF FILLET WELD	LINEAL INS. OF WELD TO DEVELOP TENSILE STRENGTH	SECTION MODULUS S	MOMENT IN INCH-LBS. THAT BEAM WILL RESIST M=S×18000	EQUIVALENT STRESS IN FLANGE WELD F= M/DEPTH	LIN. INS. OF WELD TO DEVELOP STRESS F (ONE FLANGE)
24" @ 105.9#	30.98	THESE	⅝		234.30	4217400	175730	59
24" @ 79.9#	23.33	SECTIONS	½		173.93	3130740	130450	44
20" @ 81.4#	23.74	SELDOM	½		146.63	2639340	131970	44
20" @ 65.4#	19.08	USED	⅜		116.96	2106100	105260	36
18" @ 75.6#	22.04	FOR	½		126.87	2283660	126870	43
18" @ 54.7#	15.94	TENSION	⅜		88.39	1591020	88390	30
15" @ 60.8#	17.68	3/8240	½	107	81.20	1461600	97440	33
15" @ 42.9#	12.49	224820	⅜	75	58.91	1060380	70700	24
12" @ 40.8#	11.84	213120	½	72	44.82	806760	67230	23
12" @ 31.8#	9.26	166680	⅜	56	35.97	647460	53940	18
10" @ 25.4#	7.38	132840	⅜	54	24.42	439560	43960	18
9" @ 21.8#	6.32	113760	⅜	46	18.87	339660	37740	16
8" @ 18.4#	5.34	96120	⅜	48	14.33	257940	32200	16
7" @ 15.3#	4.43	79740	⅜	40	10.34	186120	26590	14
6" @ 12.5#	3.61	64980	⅜	33	7.27	130860	21810	11

FOR ⅜ WELD ASSUMED WORKING STRESS PER LIN. IN. IS 3000#, FOR ½ WELD 2500#, FOR ⅝ WELD 2000#

Table P

flange connection. This is obviously so difficult and so expensive in the larger rolled beams that the designer should consider the advisability of a less rigid connection that will have some flexure and then the beam can be figured as a simple span.

Our practice in designing is to adopt the unit work-



NOTE (a) IN DETAILING, SPECIFY 1 MORE ON EACH LINE OF WELD THAN IS CALLED FOR IN TABLE
(b) IF VERTICAL DISTANCE BETWEEN WELDS FOR BENDING BE LESS THAN DEPTH OF BEAM, LENGTHS OF WELDS SHOULD BE INCREASED ACCORDINGLY

BEAM.	TENSION				BENDING			
	AREA.	TENSILE STRENGTH AT 18000 #/□"	SUITABLE SIZE OF FILLET WELD	LINEAL INS OF WELD TO DEVELOP TENSILE STRENGTH	SECTION MODULUS S	MOMENT IN INCH-LBS. THAT BEAM WILL RESIST M=S×18000	EQUIVALENT STRESS IN FLANGE WELD F=M/DEPTH	LIN. INS. OF WELD TO DEVELOP STRESS F (ONE FLANGE)
24 @ 70#	20.62	THESE	⅝		165.66	2945880	123570	42
22 @ 58#	17.14	SECTIONS	⅝		124.67	2244060	102570	35
20 @ 56#	16.51	SELDOM	⅝		109.77	1966860	98340	33
18 @ 47#	13.9	USED	⅝		85.18	1533240	85470	29
16 @ 35#	10.29	FOR	¼		55.15	992340	62770	22
15 @ 36#	10.61	TENSION	⅝		55.12	992160	66410	27
14 @ 30#	8.99		¼		42.43	764220	55110	28
12 @ 25#	7.44	133,920	¼	67	31.16	560880	47220	24
10 @ 21#	6.28	113,040	¼	57	21.84	393120	39710	20
9 @ 20.5#	6.09	109,620	¼	55	19.22	345960	38440	20
8 @ 17.5#	5.2	93,600	¼	47	14.45	258740	32470	17

FOR ⅜ WELD ASSUMED WORKING STRESS PER LIN. IN. IS 3000#, FOR ½ WELD 2800#, FOR ⅝ WELD 2600#

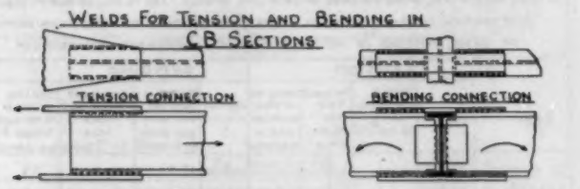
Table Q

ing stresses per lineal inch in fillet welds as recommended by the American Welding Society:

2000 lb. for 1/ 4-in. welds
2500 lb. for 5/16-in. welds
and 3000 lb. for 3/ 8-in. welds

We standardize on these sizes of fillets. If heavier fillet welds are required, special instructions are issued regarding size of electrode, peening or other procedure and operators are selected having the necessary experience. Sometimes where longitudinal and transverse fillets act together the allowable unit stresses for the transverse shear are taken 500 lb. per in. less than those for longitudinal shear which are given above. This is not because fillets are weaker in transverse shear—probably the reverse is true—but because there is a tendency for the transverse fillet to do the lion's share of the work and the lower unit stress results in more transverse fillet. In the shop, the member can be turned around to make it easy to apply the weld, but field welds must be done with members in the final position. We try to avoid overhead welds. If they must be done, then operators with that sort of experience are used. We find it convenient to have sufficient field holes inserted to enable the structure to be bolted and plumbed in the field prior to field welding. We insert these field holes in the details rather than the main material, as this makes it unnecessary to handle the main material to the shop punches. Sometimes it pays to put the holes in the main material. There are examples, as in the case of end connection angles for small beams, where good bolts in the field holes provided are sufficient to take the end reaction without any field welding.

Table "S" shows the manner in which shear can be transferred from the end of a beam by a pair of connection angles. The connection angles are shop welded to the web along the vertical edge of the leg and for 1½ in. horizontally at the top and bottom edges. The calculations are based on three sizes of fillets, ¼ in., 5/16 in. and ⅜ in., the thickness of the



NOTE (a) IN DETAILING, SPECIFY ½" MORE ON EACH LINE OF WELD THAN IS CALLED FOR IN TABLE.
(b) IF VERTICAL DISTANCE BETWEEN WELDS FOR BENDING BE LESS THAN DEPTH OF BEAM, LENGTHS OF WELDS SHOULD BE INCREASED ACCORDINGLY.

BEAM	TENSION AREA	TENSION TENSILE STRENGTH AT 18000#/in²	TENSION SUITABLE SIZE OF FILLET WELD	TENSION LINEAL INS. OF WELD TO DEVELOP TENSILE STRENGTH	BENDING SECTION MODULUS S	BENDING MOMENT IN INCH-LBS. THAT BEAM WILL RESIST M=S×18000	BENDING EQUIVALENT STRESS IN FLANGE WELD F=M/DEPTH	BENDING LIN. INS. OF WELD TO DEVELOP STRESS F (ONE FLANGE)
24 @ 70#	20.58	THESE SECTIONS	½		162.8	2,930,000	122,200	41
21 @ 58#	17.05	SELDOM USED	½		120.3	2,165,000	103,000	35
18 @ 47#	13.82	FOR TENSION	½		85.4	1,539,000	85,300	29
16 @ 35#	10.29	185,000	½	62	54.7	984,000	61,600	21
14 @ 30#	8.82	160,000	½	54	41.8	753,000	54,000	18
12 @ 25#	7.34	132,000	½	44	30.7	552,000	46,300	16
10 @ 21#	6.17	111,000	⅜	45	21.7	390,000	39,400	16

FOR ¼" WELD ASSUMED WORKING STRESS PER LIN. IN. IS 3000# FOR ⅜" WELD 2500#, FOR ¼" WELD 2000#.

Table R

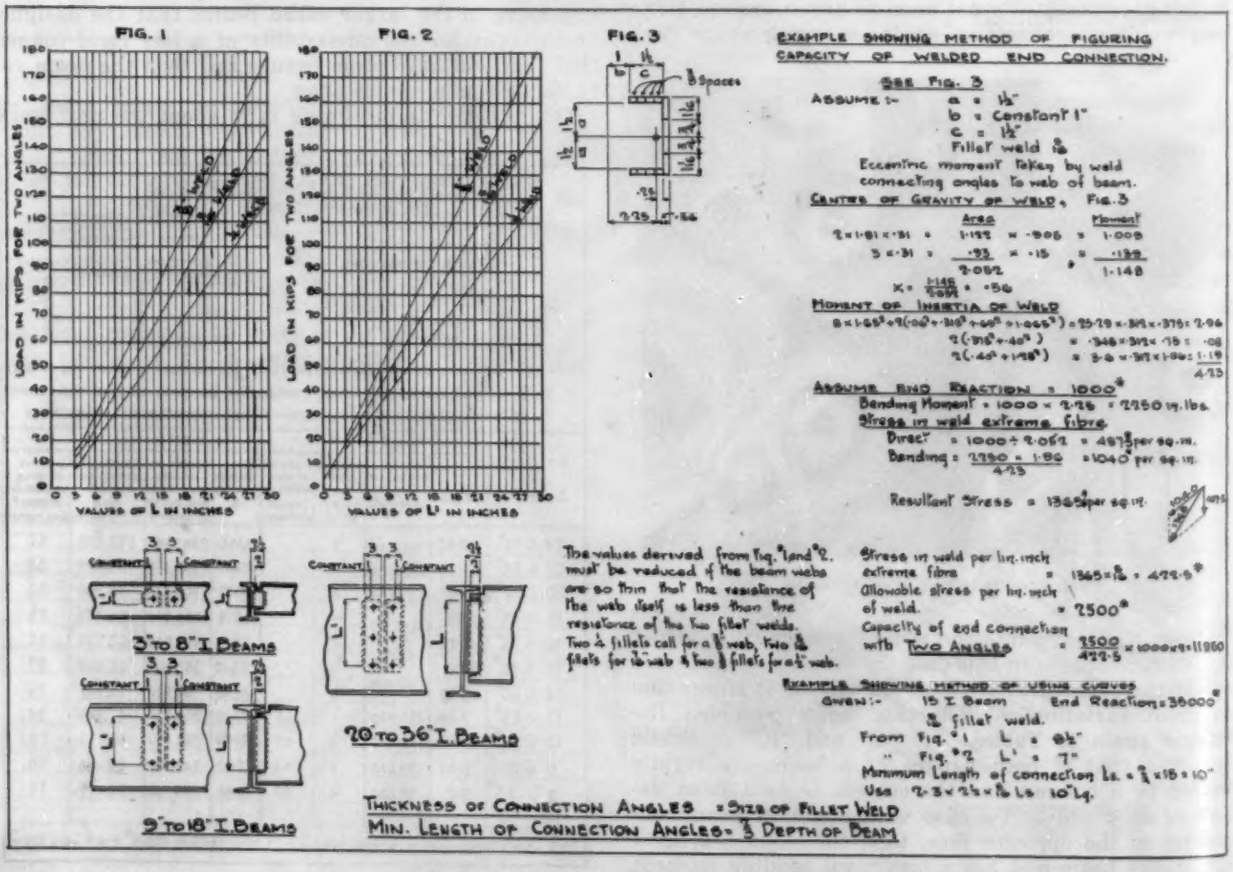


FIG. 1
FIG. 2
FIG. 3
LOAD IN KIPS FOR TWO ANGLES
VALUES OF L IN INCHES
VALUES OF L' IN INCHES
5 Spaces
EXAMPLE SHOWING METHOD OF FIGURING CAPACITY OF WELDED END CONNECTION.
SEE FIG. 3
ASSUME:- a = ½"
b = Constant 1"
c = ½"
Fillet weld ⅜
Eccentric moment taken by weld connecting angles to web of beam.
CENTER OF GRAVITY OF WELD, FIG. 3
MOMENT OF INERTIA OF WELD
ASSUME END REACTION = 1000#
Bending Moment = 1000 × 2.75 = 2750 in. lbs.
Stress in weld extreme fibre.
Direct = 1000 ÷ 2.062 = 487# per sq. in.
Bending = 2750 ÷ 1.90 / 4.23 = 1040 per sq. in.
Resultant Stress = 1365# per sq. in.
3" TO 8" I. BEAMS
9" TO 18" I. BEAMS
20" TO 36" I. BEAMS
The values derived from Fig. 1 and 2 must be reduced if the beam webs are so thin that the resistance of the web itself is less than the resistance of the two fillet welds. Two ¼ fillets call for a ½" web, two ⅜ fillets for ⅝" web & two ½ fillets for a ¾" web.
Stress in weld per lin. inch extreme fibre = 1365 × ⅜ = 422.5#
Allowable stress per lin. inch of weld. = 2500#
Capacity of end connection with TWO ANGLES = 2500/422.5 × 1000 = 11,860#
EXAMPLE SHOWING METHOD OF USING CURVES
GIVEN:- 15 I. Beam End Reaction = 36000#
⅜ fillet weld.
From Fig. 1 L = 8½"
" Fig. 2 L' = 7"
Minimum Length of connection L₂ = ⅝ × 18 = 10"
Use 2-3 × 2½ × ⅜ Ls 10" Lg.
THICKNESS OF CONNECTION ANGLES = SIZE OF FILLET WELD
MIN. LENGTH OF CONNECTION ANGLES = ⅝ DEPTH OF BEAM

Table S—Welded Web Connection Angles for Beams

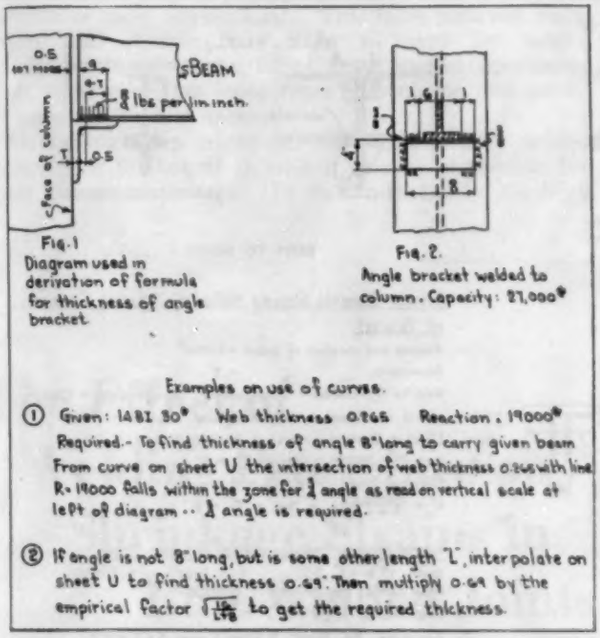

BEAM
8 lbs per lin. inch.
face of column
Fig. 1
Diagram used in derivation of formula for thickness of angle bracket.
Fig. 2.
Angle bracket welded to column. Capacity: 27,000#
Examples on use of curves.
① Given: 14BI 30# Web thickness 0.265 Reaction. 19000#
Required.- To find thickness of angle 8" long to carry given beam
From curve on sheet U the intersection of web thickness 0.265 with line R=19000 falls within the zone for ½ angle as read on vertical scale at left of diagram.. ½ angle is required.
② If angle is not 8" long, but is some other length "L", interpolate on sheet U to find thickness 0.69". Then multiply 0.69 by the empirical factor √(10/L8) to get the required thickness.

Table T—Welded Shelf Angle Connections—Method of Determining Thickness of Angle Bracket Without Stiffeners

connection angle depending on the fillet. The strength of the shop weld is figured by its moment of inertia, as shown in Fig. 3. The minimum length of connection angle is arbitrarily fixed at two-thirds of the depth of the beam. Its required theoretical length is dependent on the strength of the shop weld and the required length of field weld is figured separately, being always less than the length of the connection angles. The 3-in. outstanding legs of the connection angles are not field welded near the roots of angles, so that slight deformation of the angles is quite possible, thus allowing for deflection in the beam. Figs. 1 and 2 would indicate that loads up to 180,000 lb. can theoretically be carried by such angles. It would be well to have tests made before following this in practice. Another precaution is also necessary in applying this table. The 5/16-in. fillets are figured to shear diagonally at 45 deg. across the root, so that failure of two fillets on opposite sides of the web would mean shearing of a total thickness of 7/16 in. Thus for 5/16-in. fillets the web should be at least 7/16 in. thick and if it is thinner than this, then the size of fillet *can* be and the strength *must* be correspondingly reduced.

Tables "T" and "U," taken together, enable us to figure the size and thickness of the shelf angle required to carry a given reaction from a beam of known section. Fig. 1 on Table T illustrates the method. First of all, from the reaction and the depth of the beam and the thickness of its web we can figure by the ordinary web crippling formula the length "a" of beam that must theoretically bear on the shelf if the web is to be unstiffened. Then we assume that the bending in the shelf occurs at the edge of the fillet on the horizontal leg and that this fillet is ½ in. To suit such conditions a formula is derived to give the required thickness of shelf angle. The results of this formula are plotted on diagrams, one diagram for each depth of beam. The diagrams for 14-in. and 15-in. beams are shown on Table U. At the bottom of Table T is an actual example showing how the thickness of shelf angle is determined if the length of the angle is 8 in., which is the length on which Table U is based. The example also shows the correction that is to be applied to the thickness if the length is different to 8 in. It will be noted that while distance "a" is the initial step in the calculation, yet it is not really necessary to find it if Table U is used. We have other tables similar to U for other depths of beams. These calculations for size of shelf angles will apply to riveted construction as well as welded. Table T shows also how shelf angles may be welded to columns to resist a reaction of 27,000 lb., the calculation of this strength takes into account the tendency of the shelf angle to overturn outward. Greater strengths can be obtained by increasing the size of the shelf or of the weld, but it is doubtful if a shelf would be used in practice for much greater loads.

Table V shows welded T shelf brackets. It is assumed that the vertical surface of the T that bears against the column will be sawn or machined to give satisfactory bearing. As in the case of shelf angles, it will be necessary to make sure that the web of the beam will not fail by crippling. The T will not deflect like a shelf angle, so that the eccentricity may be assumed as due to a load whose center is at the center of the bearing length of the beam web. The outward pull produced at the top of the T by this moment is resisted by the weld on the underside of the flange, while the vertical reaction is resisted by the stem weld. The method of figuring these welds and the consequent size of T shelf is shown on Table V. You will note that the minimum thickness of the stem of the T is controlled by the size of weld used. If the stem weld is made longer than the table indicates to be necessary, then the flange weld can be somewhat reduced. With shelf connections as shown on Tables T and V, the top of the beam is held by a lug angle, not welded near the root, thus providing some flexure for the deflection of the beam.

Tables W and X are samples of sheets showing

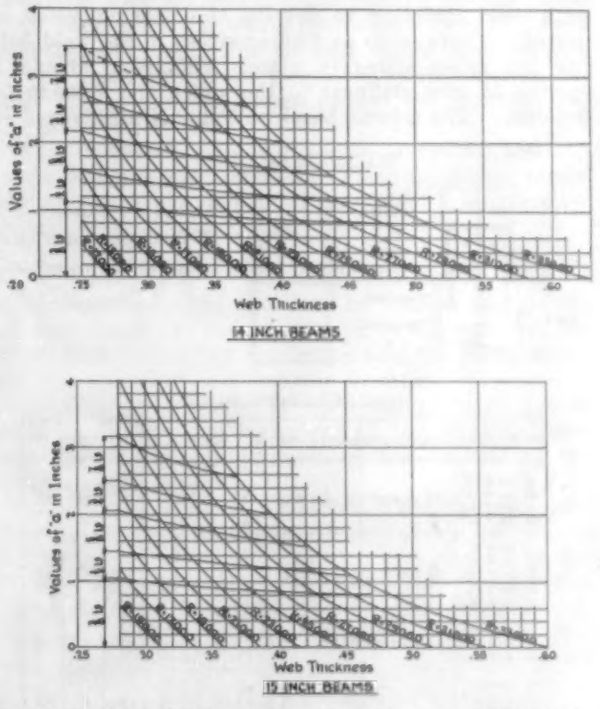
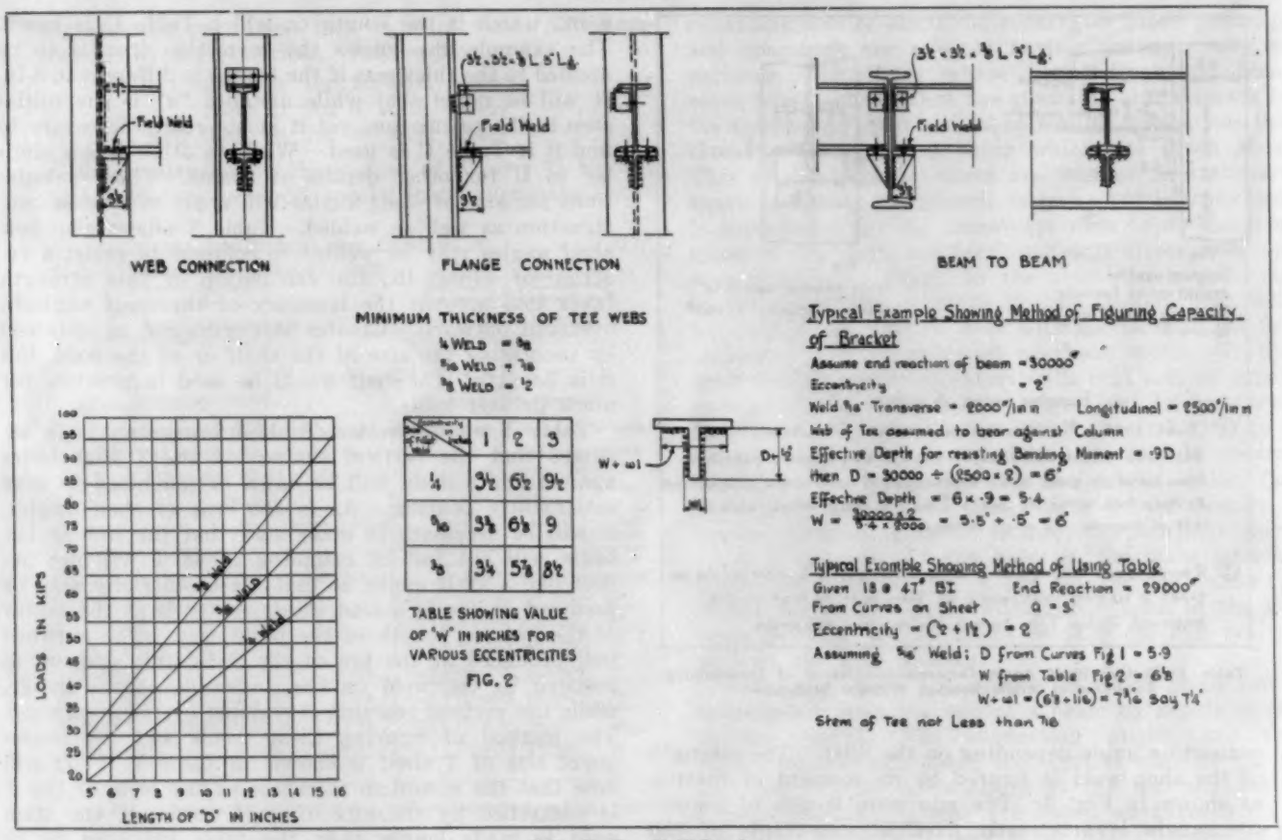


Table U—Curves Showing Capacity of Shelf Angle Brackets Without Stiffeners for Shelf Thicknesses for 14" and 15" Beams

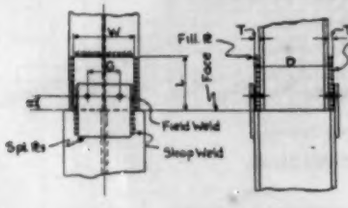

WEB CONNECTION
FLANGE CONNECTION
BEAM TO BEAM
Field Weld
MINIMUM THICKNESS OF TEE WEBS
¼ WELD = ⅜
5/16 WELD = 7/16
⅜ WELD = ½
LOADS IN KIPS
LENGTH OF "D" IN INCHES
TABLE SHOWING VALUE OF "W" IN INCHES FOR VARIOUS ECCENTRICITIES
FIG. 2
Typical Example Showing Method of Figuring Capacity of Bracket
Assume end reaction of beam = 30000#
Eccentricity = 2"
Weld ⅜" Transverse = 2000#/lin in Longitudinal = 2500#/lin in
Web of Tee assumed to bear against Column
Effective Depth for resisting Bending Moment = .9D
then D = 30000 ÷ (2500 × 2) = 6"
Effective Depth = 6 × .9 = 5.4
W = 30000 × 2 / 5.4 × 8000 = 5.5" + .5" = 6"
Typical Example Showing Method of Using Table
Given 18 @ 47# BI End Reaction = 29000#
From Curves on Sheet a = 3"
Eccentricity = (2 + 1½) = 2
Assuming ⅝" Weld; D from Curves Fig 1 = 5.9
W from Table Fig 2 = 6⅛
W + a1 = (6⅛ + 1/16) = 7 1/16 say 7¼"
Stem of Tee not Less than ⅞

	1	2	3
¼	3½	6½	9½
5/16	3⅜	6⅛	9
⅜	3¼	5⅞	8½

Table V—Tee Shelf Brackets

column splices and column bases. The column splices shown cover only the more common cases of columns from 6 by 6 to 14 by 14. The fillers are, of course, necessary only where the columns spliced differ in depth. The fillers are shop welded to the upper column and faced with it. The filler is welded to the column with weld sufficient to develop the bearing value required. There is no particular stress in the weld holding the splice plates in place. This weld should be enough to give stiffness to the splice and thus to the building. The column bases on Table X are figured for loads per square inch on concrete of 500 lb. and 600 lb., those bases for 600 lb. being necessarily the thicker. We usually put anchor bolts in our column bases, but

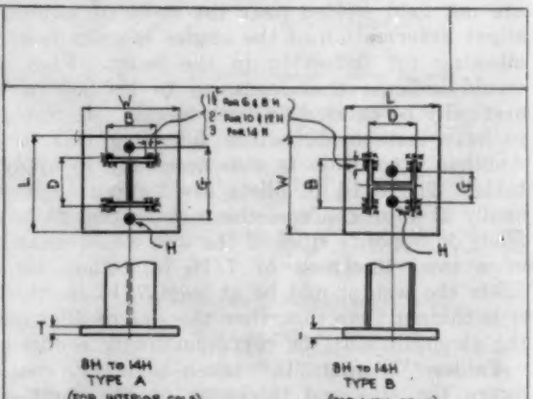
BETHLEHEM COLUMNS



WELDED COLUMN SPLICES

UPPER COLUMN	LOWER COLUMN	SPLICE PLATES	T	W	L	B	G	D
6" BH @ 20# 6⅛" BH @ 25# 6⅛" BH @ 36.5# 6⅛" BH @ 50#	7⅛" BH @ 32#	4½ × ⅜ R. 8'-1½	⅜ ½ ⅝	⅜	5½"	2½"	2½"	7½"
7⅛" BH @ 32# 8" BH @ 38# 8⅛" BH @ 39.5# 8⅛" BH @ 44# 8⅛" BH @ 48.5#	9⅛" BH @ 48.5#	6 × ⅜ R. 8'-1½	⅜ ½ ⅝	½	5½" 6½" 7" 8½" 10½"	2½"	3½"	9½"
9⅛" BH @ 49.5# 10" BH @ 55# 10⅛" BH @ 60.5#	11⅛" BH @ 65.5#	8 × ⅜ R. 8'-1½	⅜ ½	⅝	9½" 10½" 1'-0½"	2½"	5"	11⅛"
11⅛" BH @ 65.5# 11⅛" BH @ 71.5# 12" BH @ 79#	13⅛" BH @ 84#	10 × ⅜ R. 10'-1½	⅜ ½	¾	1'-1½" 1'-2½" 1'-4½"	3"	5"	13⅛"

Table W—Welded Splices



SIZE OF COL D × B	BASE CAPACITY 500#/□"	BASE CAPACITY 600#/□"	DIMENSIONS L	W	T 500	T 600	G	DIAM OF HOLES H	SIZE OF ANCHORS
6×6	72,000	86,400	12	12	1	1		1¼	1Φ × 1'-6
	98,000	17,600	14	14	1¼	1¼		1¼	1Φ × 1'-6
8×8	128,000	153,600	16	16	1¼	1¼		1¼	1Φ × 1'-6
	168,000	194,400	18	18	1½	1½	4" FROM TOP OF BASE	1¼	1Φ × 1'-6
	200,000	240,000	20	20	1¾	2		1¼	1Φ × 1'-6
10×10	200,000	240,000	20	20	1½	1¾		1¼	1Φ × 2'-6
	248,000	290,400	22	22	1¾	2		1¼	1Φ × 2'-6
12×12	288,000	345,600	24	24	1¾	2		1½	1Φ × 2'-6
	338,000	405,600	26	26	2	2½		1½	1Φ × 2'-6
14×14	338,000	405,600	26	26	1¾	2		1½	1Φ × 2'-6
	392,000	470,000	28	28	2	2½		1½	1Φ × 2'-6
	450,000	540,000	30	30	2½	2½		1½	1Φ × 2'-6

Table X—Welded Column Bases—Dimensions and Safe Loads for Standard Slab Bases

sometimes these are omitted. This table does not show larger and thicker base slabs as used for larger columns. These larger bases need special consideration; they are often loose from the column and set in advance by special means.

Something more might be said about making welded connections for beams in such a way as to provide for them being continuous. In fact, practically all high buildings are stiffened by making the riveted connection of beams to columns in such a manner. No doubt suitable welded connections can be devised for this purpose, but this is one of the fields where very little is to be gained by generalization. Each building has its own peculiar stiffening problem and we had best leave these problems to be worked out each against its own background.

The Effect of Welding Procedure on Shrinkage Strains in Butt Welded Joints

By C. H. JENNINGS

✦ This paper is to be presented at the Annual Meeting of the A. W. S. by C. H. Jennings, Research Labs., Westinghouse Electric & Mfg. Company.

Introduction

THE arc welding of butt type joints in such a manner as to develop low shrinkage strains in the welded joint and surrounding structure has long been a problem to the welding engineer and welding operator. Welding strains of this type have been the cause of many limitations in welded design and the cause of many failures in repair jobs. Consequently, it was desirable that some information be obtained on the possibility of reducing such shrinkage strains by employing the proper welding procedure.

It is well known that the magnitude of the shrinkage strains obtained in a butt weld, for any given welding procedure, depends primarily upon the rigidity of the joint. Also, it is evident that if one welding procedure is superior to another in relieving shrinkage strains in a certain type of butt joint, it will also be superior for other types of butt joints. Because of these facts it was possible to obtain the desired information regarding the effect of welding procedure on the shrinkage strains in butt welded joints by conducting tests on a single type of joint.

Test Specimens

The test specimen used in the investigation consisted of a rigid joint of the 60 degree double vee type as shown by Fig. 1. This type of specimen was chosen because of its simplicity, its high degree of rigidity, and its ready adaptability for the actual measurement of shrinkage strains.

The specimens were prepared from 1½ in. thick hot-rolled steel plates by means of an automatic gas cutting torch. No machining was done on any of the specimens. Strain gage holes were drilled on both sides of the center bar of each specimen as shown in Fig. 1. These gage holes were so located that strain gage readings taken between them in a direction at right angles to the axis of the weld measured unit deformations of the center bar. Also, because the deformation of the center bar was a function of the amount of contraction of the welds, these readings gave a satisfactory means by which the different welding procedures could be compared.

Test Procedure and Results

Six types of welding procedures were investigated and they are illustrated and described in detail in Figs. 2 to 4, inclusive. The variations in the different procedures laid in the method of depositing the weld metal and the application of peening in certain cases. The procedure of making half the weld on both sides of the joint before completing the weld on the first side, as shown in Figs. 2 to 4, inclusive, was carried out in an effort to eliminate bending stresses as much as possible.

The test procedure consisted essentially of taking strain gage readings on each specimen before and after welding by means of a Berry strain gage with a 1-in. gage length. Care was taken during the welding processes to keep the outer portions of all the specimens at approximately the same temperature in order to eliminate the effect of temperature variations in the specimens.

All welds were made by using 5/32-in. diameter bare, low-carbon steel electrodes. The welding currents used for all but the vertical weave procedure (Type IV) were about 150 amperes. The current values used for the vertical weave procedure were about 100 amperes, because higher current values caused the joint to become excessively hot.

Three tests were made of each procedure and the results obtained are tabulated in Table I. Actual strain gage readings are tabulated in Table I in place of stresses or unit elongations.

Discussion of Results

Examination of the test data in Table I reveals the fact that there was some variation in the readings obtained from individual specimens and that each specimen was subjected to a bending moment.

The variations in the strain readings were due to two things: first, the technique of the welding operator, and, second, the inherent method underlying the process of arc welding.

The effect of welding technique is easily understood when one considers the many factors that enter during the process of welding. The operator may hold the arc longer in one place than another, causing excessive heating at certain points, or he may vary the width of the beads and the amount of overlap between successive beads. In cases where peening is done, the operator may peen certain portions of the weld more than others. All of the above items would greatly affect the stress distribution along the joint.

The inherent method of arc welding which consists of depositing small quantities of metal at a time affects the distribution of stress because the progressive laying of a bead of weld metal along a joint causes progressive heating and cooling of the joint. Uneven heating and cooling of this type ultimately results in a non-uniform stress distribution.

The condition of non-uniform stress distribution is clearly shown by the curves in Fig. 5. Each curve shown is typical of the type of stress distribution that was obtained by its particular type of welding procedure. The strain gage values for each point plotted in the curves are the average readings of two points on the same side of the specimen and directly across the weld from each other. (The first point on each curve is the average of readings 1 and 4, the second point of each curve is the average of readings 2 and 5,

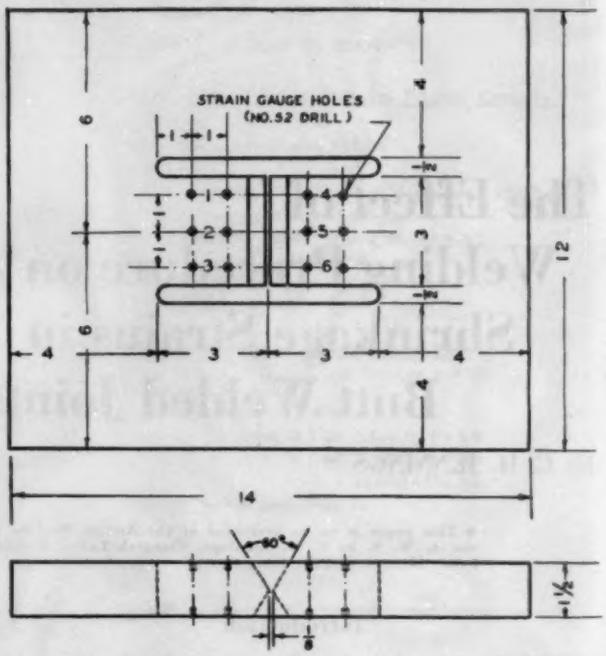


Fig. 1—Specimen for Measuring Welding Strains

and the third point on each curve is the average of readings 3 and 6.)

The curves for the cross weave, the horizontal layer, the vertical layer, and the vertical weave procedures (Types I, II, III and IV) indicated that the stress distribution along the welds was distinctly convex, with the maximum stress occurring near the center of the weld. The peened horizontal layer procedure (Type V) showed a tendency toward the convex stress distribution, although it was not as pronounced as in some of the other cases. The peened vertical layer procedure (Type VI) showed an almost uniform stress distribution along the weld. The more uniform stress distribution as obtained from the peened weld procedures was the result of the peening operation. If peening was carried out properly it would undoubtedly result in a uniform stress distribution along the weld.

The fact that the shrinkage stresses are not evenly distributed along butt welds probably accounts for numerous failures which occur in the centers of such welds. If the stresses along the butt welds could be reduced, or more evenly distributed along the weld, the peak stress near the center would be lowered and consequently many failures might be avoided.

The bending moments present in the specimens were caused by the inability to weld both sides of the vee at the same time. The particular welding procedure used in this investigation gave fairly good results, but it is felt that better results might have been obtained if half the vee on one side had been welded first, the entire vee on the reverse side next, and the vee on the first side completed last.

As previously mentioned, the strain gage readings

Table I

STRAIN GAGE READINGS ON SPECIMENS

Welding Procedure	Spec. No.	Side	Strain Gage Readings: Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Ave.
Cross Weave (Type I)	1	A	7.5	17.4	10.8	13.2	18.6	12.0	13.3
		B	6.3	11.5	8.1	5.7	9.9	16.5	9.7
								Ave.	11.5
Cross Weave (Type I)	2	A	12.5	9.6	9.2	11.2	8.5	7.7	9.8
		B	13.1	11.3	12.8	9.1	12.5	8.0	11.1
								Ave.	10.5
Cross Weave (Type I)	3	A	15.2	12.3	16.8	10.8	17.0	16.6	14.7
		B	8.0	8.9	8.8	6.6	9.0	6.5	8.1
								Ave.	11.4
Horizontal Layer (Type II)	4†	A	21.3	18.9	20.9	10.9	17.2	13.6	17.1
		B	20.9	12.8	6.2	10.1	7.3	6.4	10.6
								Ave.	13.8
Horizontal Layer (Type II)	5	A	12.3	14.8	9.4	12.9	19.1	14.5	13.8
		B	10.7	9.2	6.4	13.8	13.9	10.4	10.7
								Ave.	12.3
Horizontal Layer (Type II)	6	A	4.5	5.4	5.4	3.2	16.1	6.2	6.7
		B	13.0	17.8	10.7	10.7	17.2	15.4	14.1
								Ave.	10.4
Vertical Layer (Type III)	7	A	10.7	10.2	12.5	9.7	12.0	10.2	10.7
		B	4.2	9.6	9.4	9.5	10.9	7.0	8.4
								Ave.	9.6
Vertical Layer (Type III)	8	A	5.4	6.6	3.4	7.3	12.5	6.8	7.0
		B	10.3	12.7	12.1	12.3	11.0	11.2	11.6
								Ave.	9.3
Vertical Layer (Type III)	9	A	5.6	8.5	4.2	2.6	9.8	10.1	6.8
		B	10.2	10.2	5.6	6.3	6.5	6.8	7.6
								Ave.	7.2
Vertical Weave (Type IV)	10	A	16.4	19.8	16.3	17.6	20.6	16.9	17.9
		B	9.8	13.3	12.8	11.3	19.6	11.5	13.1
								Ave.	15.5
Vertical Weave (Type IV)	11	A	17.1	17.8	13.4	17.5	17.5	14.1	16.2
		B	10.1	13.6	10.7	13.5	14.7	8.4	11.3
								Ave.	14.0
Vertical Weave (Type IV)	12	A	10.8	23.8	17.6	8.9	13.5	15.3	15.0
		B	11.5	14.1	11.1	15.8	5.9	8.0	11.1
								Ave.	13.1
Peened Horizontal Layer (Type V)	13	A	10.1	9.0	10.1	8.8	10.6	3.4	8.6
		B	4.7	6.3	12.0	4.6	9.2	5.0	7.0
								Ave.	7.8
Peened Horizontal Layer (Type V)	14	A	4.0	3.9	4.7	2.5	3.9	12.7	5.3
		B	12.5	7.6	8.2	8.7	9.3	...	9.3
								Ave.	7.3
Peened Horizontal Layer (Type V)	15	A	2.5	10.5	8.8	2.3	9.9	...	6.8
		B	7.0	9.9	6.7	5.9	8.0	...	7.5
								Ave.	7.2
Peened Vertical Layer (Type VI)	16	A	2.0	3.8	5.1	7.0	5.1	7.0	5.0
		B	8.4	8.5	7.1	3.6	7.5	4.7	5.8
								Ave.	5.4
Peened Vertical Layer (Type VI)	17	A	0.3*	5.8	5.3	4.2	5.7	8.0	5.8
		B	0.7*	3.0	8.0	4.3	6.5	3.5	5.1
								Ave.	5.5
Peened Vertical Layer (Type VI)	18	A	8.5	5.9	3.7	6.3	7.4	5.4	6.2
		B	3.3	6.1	3.5	2.6	3.1	4.7	3.9
								Ave.	5.1

*Not included in the average of the readings.

†Specimen cracked—the tabulated figures are based upon the reading taken after welding plus a factor 5 which corresponds to the strain gage reading equivalent to yielding (30,000 lb. sq. in. stress) in the specimen.

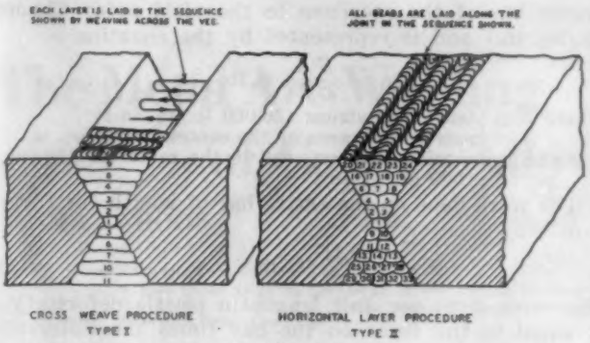

EACH LAYER IS LAID IN THE SEQUENCE SHOWN BY WEAVING ACROSS THE VEE
ALL BEADS ARE LAID ALONG THE JOINT IN THE SEQUENCE SHOWN.
CROSS WEAVE PROCEDURE TYPE I
HORIZONTAL LAYER PROCEDURE TYPE II

Fig. 2

taken are a measure of the amount of strain produced by the various welding procedures, and because the largest strain readings were obtained from procedures which produced the largest strains, the procedures which gave the smallest strain readings were considered the most satisfactory procedures. The comparison of the relative values of the different welding procedures by the direct comparison of the strain readings taken was not entirely satisfactory because the specimens were stressed beyond their yield point by the shrinkage of the welds, and the relation of stress and strain was not the same before and after yielding

Table II

WORK DONE IN DEFORMING THE CENTER BARS OF THE SPECIMENS

Procedure	Average Strain Readings Three Specimens	*Unit Elong. Corres. to Strain Reading	Work Done in Elastic Deform., Ft./Lb.	Work Done in Plastic Deform., Ft./Lb.	Total Work, Ft./Lb.	Per Cent Work Done as Compared to Type I Procedure
Type I Cross weave	11.1	0.00222	33.8	82.5	116.3	100.0
Type II Horizontal layer	12.2	0.00244	33.8	97.4	131.2	113.0
Type III Vertical layer	8.7	0.00174	33.8	50.0	83.8	72.0
Type IV Vertical weave	14.2	0.00284	33.8	124.2	158.0	136.0
Type V Peened horizontal layer	7.4	0.00148	33.8	32.4	66.2	57.0
Type VI Peened vertical layer	5.3	0.00106	33.8	4.1	37.9	32.0

*Unit elongation = strain reading $\times \frac{2}{10{,}000}$

occurred. As a result the work done in deforming (or stretching) the center bars of the specimens was used as a means of comparison.

The method for computing the work done on the center bar is given in Appendix I and the results obtained for the different procedures are given in Table II.

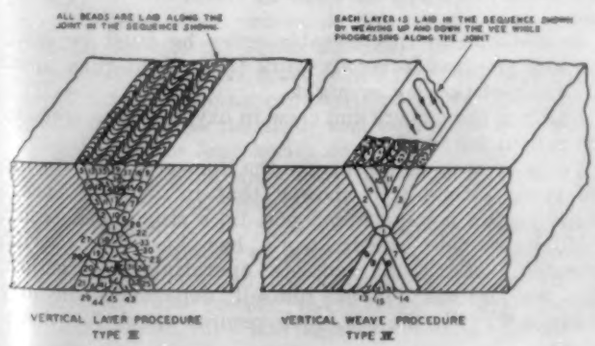

ALL BEADS ARE LAID ALONG THE JOINT IN THE SEQUENCE SHOWN.
EACH LAYER IS LAID IN THE SEQUENCE SHOWN BY WEAVING UP AND DOWN THE VEE WHILE PROGRESSING ALONG THE JOINT
VERTICAL LAYER PROCEDURE TYPE III
VERTICAL WEAVE PROCEDURE TYPE IV

Fig. 3

Inspection of the last two columns in Table II readily shows the relative differences between the various welding procedures. It will be noted that for the unpeened procedures the vertical layer procedure (Type III) gave the most satisfactory results and that for the peened procedures the peened vertical layer procedure (Type VI) gave the most satisfactory results. The effect of peening as a means of relieving residual stresses is clearly brought out in these results.

In applying the different welding procedures to different types of butt joints, the relative differences between them, as given in this paper, will not remain the same in all cases. It is reasonable to assume, however, that the procedures which give the best results in this investigation will also give the best results on other types of butt joints.

It should also be noted that this investigation has not attempted to make any differentiation as to the relative strengths of the different welding procedures. It is felt, however, that if the welds are properly made very little differences in strength will be obtained from the different procedures.

Conclusions

From the results of this investigation the following conclusions are obtained:

1. There is very little difference between the shrinkage strains as obtained by the cross weave procedure (Type I) and the horizontal layer procedure (Type II).

2. Smaller shrinkage strains were obtained by the vertical layer procedure (Type III) than by the cross weave, horizontal layer and vertical weave procedures.

3. The vertical weave procedure (Type IV) developed the greatest shrinkage strains.

4. The peened horizontal layer procedure (Type V) developed smaller shrinkage strains than the cross weave, the horizontal layer, the vertical layer and the vertical weave procedures.

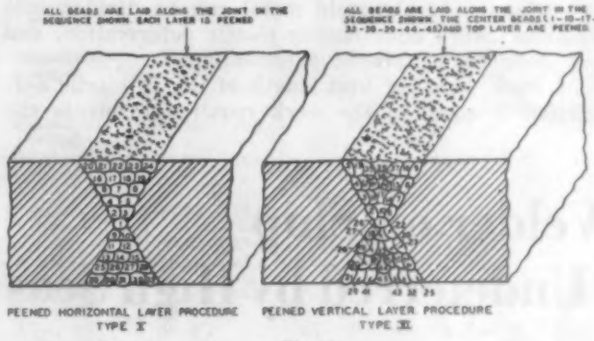

ALL BEADS ARE LAID ALONG THE JOINT IN THE SEQUENCE SHOWN. EACH LAYER IS PEENED
PEENED HORIZONTAL LAYER PROCEDURE TYPE V
PEENED VERTICAL LAYER PROCEDURE TYPE VI

Fig. 4

5. The peened vertical layer method produced the smallest shrinkage strains.

6. Peening is very effective as a means of reducing shrinkage strains in butt welds.

7. Stresses in butt welds are not evenly distributed along the joint. The exact stress distribution depends upon the rigidity of the joint and the method of welding.

8. Peening is very effective in producing a uniform stress distribution in butt welded joints.

Acknowledgment

The author wishes to give particular acknowledgment to Mr. J. M. Lessells, manager of the mechanics

division, Westinghouse Research Laboratories, and Mr. G. E. Moore for their assistance and valuable aid in conducting the investigations included in this paper.

APPENDIX

Work Done in Deforming the Center Bar of the Test Specimen

In the following discussion the effect of stress concentrations is neglected, and it is assumed that the stress is evenly distributed across the center bar. The assumption of a uniform stress distribution is admitted to be incorrect in some cases, but it is satisfactory for the information desired.

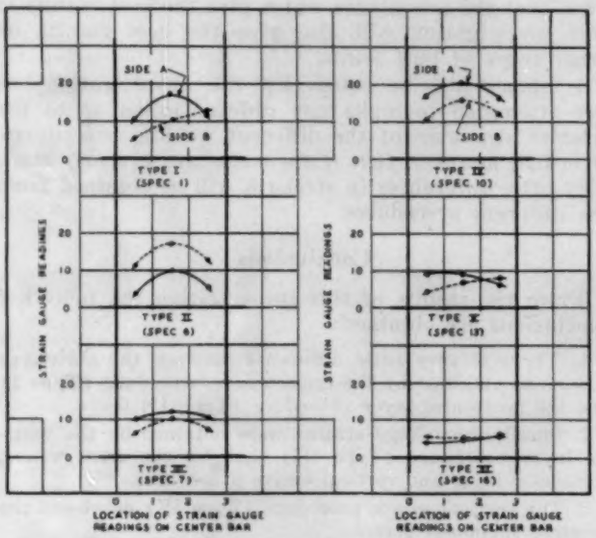


Fig. 5—Strain Distribution Curves for Butt Welds

The total work done in deforming the center bar by the shrinkage of the weld metal can be divided into two parts; work done during elastic deformation, and work done during plastic deformation.

The work done per unit length of bar in elastic deformation is equal to the work required to stress the center bar of the specimen to the yield point (30,000 lb./sq. in.) and is represented by the equation

$$W_E = \frac{S^2 A}{24\,E} \text{ ft. lb.}$$

where S = yield point stress (30,000 lb./sq. in.)
A = cross-section area of the center bar in sq. in.
E = modulus of elasticity of the material (30,000,000 lb./sq. in.)

The work done on the entire bar of length l is therefore

$$W_E = \frac{S^2 A l}{24\,E} \text{ ft. lb. } \ldots\ldots\ldots\ldots (1)$$

The work done per unit length in plastic deformation is equal to the force on the bar times the difference between the measured elongation and the elongation to produce a stress equal to the yield point of the material

$$W_P = \frac{SA}{12}\left(\epsilon - \frac{S}{E}\right) \text{ ft. lb.}$$

where ϵ is the unit elongation measured with the strain gage. The work done on the entire bar of length l is therefore

$$W_P = \frac{SAl}{E\,12}\,(E\epsilon - S) \ldots\ldots\ldots\ldots\ldots (2)$$

The total work done is equal to the sum of the elastic work and the pastic work

$$W = W_E + W_P \ldots\ldots\ldots\ldots\ldots (3)$$

$$W = \frac{S^2 Al}{24\,E} + \frac{SAl}{12\,E}\,(E\epsilon - S) \ldots\ldots (4)$$

$$W = \frac{SAl}{24\,E}\,(2E\epsilon - S) \ldots\ldots\ldots\ldots (5)$$

It is sometimes advantageous to have the work expressed as in equation (4) because it separates the works done in elastic and plastic deformation.

Example using the results of the Type I procedure and equation (4)

$S = 30{,}000$ lb./sq. in.
$A = (3)\ (1.5) = 4.5$ sq. in.
$l = 6$ inches
$E = 30{,}000{,}000$ lb./sq. in.
$\epsilon = .00222$ in. (See Table II)

$$W = \frac{(30{,}000)^2\,(4.5)\,(6)}{(24)\,(30{,}000{,}000)} + \frac{(30{,}000)\,(4.5)\,(6)}{(30{,}000{,}000)\,(12)}\,(30{,}000{,}000)\,(.00222) - 30{,}000$$

$$W = 33.8 + 82.5 = 116.3 \text{ ft. lb.}$$

Welder on Ship Undeterred by High Seas

By **F. J. FITZ GERALD**

✦ Mr. Fitz Gerald is connected with the Technical Publicity Department of the Linde Air Products Company.

PERCHED above the deck in the dummy funnel of the ocean liner "Lafayette," a truly sea-going welder and his helper ply their trade. In this room 10 ft. by 12 ft. and 7 ft. 6 in. high, is a complete and modern welding and cutting station capable of handling any work aboard ship.

To the Chief Engineer aboard this motor ship the presence of the welder means that the jobs of construction or repair that formerly had to wait until a port was reached can be done without delay then and there. To the passengers it means comfort, and freedom from the possibility of delay. The welder is responsible for all plumbing and heating piping and fittings as well as all ordinary welding repair work.

Once aboard ship the welder has dozens of different jobs. His routine work consists of a daily inspection of engine room safety equipment, the piping of all sorts, and various safety devices above and below the water line.

In addition to this sizeable order he must be ready for any emergency repair work that might turn up at any hour of the day or night.

Faith of the officers and crew in oxy-acetylene welding has a firm foundation.

Tests of welded piping on the forward deck during the vessel's trial trip showed that in spite of severe pounding not a joint failed nor did a single leak occur.

Much routine repair work has been done with despatch,—and with complete operating satisfaction. The welder has proved himself dependable in any emergency. On the sea, such records speak for themselves.

The Metal Arc Welding of Copper Alloys

By IRA T. HOOK

✦ This paper is to be presented at the Annual Meeting of the A. W. S., by Ira T. Hook, Research Engineer for the American Brass Company.

GENERAL

THE copper alloys give us perhaps the most interesting and useful set of properties possessed by any group of metals. For *durability*, we have copper itself which, better than any other metal save gold and platinum, has resisted the disintegrating action of time. Hardened with tin to form the bronze of the ancients or with silicon and manganese to form the Everdur metal of the modern metallurgist, it withstands even better the severe attack of the elements and chemical solutions.

For *beauty*, we have the deep red of copper itself or its equally beautiful cloak of pale green patina, the bright yellow of the high zinc brasses, the pleasing, distinctive bronze of the tin and low zinc alloys and the silvery white of the nickel alloys.

For *utility*, we have a rapidly spreading network of copper wires and cables which annihilates darkness in our vision and distance in our conversation, and brings the untiring energy of three thousand million slaves into our homes and workshops.

Similarly, copper gives the best *heat conductor* that we have, making the metal incomparable for industrial heat exchangers and the compact radiators or newer heating panels for our offices and homes. But with all the beauty and utility of copper alloys, a paper on them may be regarded out of place in a meeting of this kind unless we can bring to the welder in attendance some kinks of craftmanship which will enable him to go back to the shops and turn the information into a financial reward.

Scope of Paper

For this purpose, it will be necessary to confine our attention to the metal arc welding process as applied to copper alloys. Needless to say, there are many welding applications where the oxy-acetylene torch, the carbon arc, the atomic hydrogen arc or the carbon arc torch would be the correct tool to use instead of the metal arc. However, in the time available, we cannot go into these other processes, but must needs concentrate on the one particular method.

More than this, we must select from the large number of copper bearing compositions those alloys which are most useful to the trade and which are most representative of the long series of metals falling into this category. In some ways, this is not as difficult a task as it might seem, since the drastic action of the arc itself eliminates, as possible metal arc electrodes, a considerable number of alloys, enabling us at once to settle on some four or five different rods for this purpose. The base metals, not having to pass through the arc stream, are less severely used and therefore constitute a larger group.

Alloys Discussed—Metal Arc Electrodes

In selecting alloys for metal arc electrodes, we must consider primarily the requirements in the added metal whether good electrical conductivity, strength and soundness, good wear resistance or a particular color match is desired. The following list is by no means complete, but is given as representative of alloys which embody the general characteristics of a much larger list:

Name	Composition, Per Cent: Copper	Tin	Zinc	Silicon	Color	Remarks
Deoxidized Copper	Rem.	...	...	0.01 to 0.50	Copper red	May use 0.01% to 0.50% phosphorus instead of silicon
Phosphor Bronze A	Rem.	5.0	Phos. 0.05 to 0.50	...	Pale red—bronze	
Phosphor Bronze D	Rem.	10.0	0.05 to 0.50	...	Distinctive bronze color	
Ambrac	Rem.	Ni. 20.0	...	Zn. 5.0	Metal white	Carries small per cent of manganese as a deoxidizer
Everdur	Rem.	Mn. 1.0	...	Si. 3.0	Distinctive bronze color similar to Phos. Br. D.	

Alloys Discussed—Base Metals

The copper alloy sheet and variously shaped metals used as base materials are a much longer list than those considered for the welding rod.

At this stage of the welding art it is rather risky to say what alloys can be used and what cannot. Since the base metal does not have to pass through the arc stream, it is often possible to make successful welds on it even when it contains elements which are particularly sensitive to heat. The following copper alloys are given consideration as base metals herein:

Name	Composition, Per Cent: Copper	Zinc	Tin	Color	Remarks
Electrolytic of lake copper (tough pitch)	99.93	...	...	Copper red	Carries 0.03% to 0.07% oxygen in form of cuprous oxide dissolved in the solid metal
Deoxidized copper	99.50 or more	...	...	Copper red	Carries no oxygen but has 0.01% to 0.50% of phosphorus or silicon
Commercial bronze	90.00	10.0	...	Pale red—bronze	
85:15 red brass	85.00	15.0	...	Yellow with reddish blush	
Common brass	65.00 to 68.00	35.0 to 32.0	...	Yellow brass	
Muntz metal or extruded brass or bronze	59.00 to 62.00	41.0 to 38.0	...	Yellow brass	
Phosphor Bronze A	95.00	...	5.0	Pale red—bronze	Carries 0.03% to 0.50% phosphorus as a deoxidizer
Ambrac	75.00	5.0	Ni. 20.0	Metal white	Carries small percentage of manganese as a deoxidizer
Everdur	96.00	Si. 3.0	Mn. 1.0	Distinctive bronze color	

Metal Arc Electrodes—Permissible Elements

It will be noted from the above tabulation that in addition to the copper itself there are some half dozen elements alloyed therewith. Actually about one-third of the known elements will alloy with copper. In the case of some of the non-commercial elements, the action is not fully known, while in others the action in the arc is unsatisfactory. The following notes will

help in understanding the effect of the various elements:

Oxygen.—In the small amounts (.03 to 0.7 of 1 per cent) in which this element occurs in the electrolytic or tough pitch copper of commerce, its effect is beneficial. It exists in the form of cuprous oxide dissolved for the most part in the solid metal. Practically all of the copper used generally in the electrical industry, as well as that commonly used in the form of sheets and wire, is of this nature.

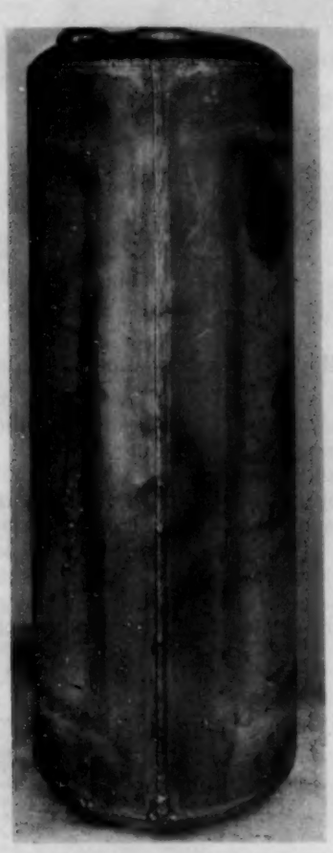


Fig. 1—12″ Diameter x 31″ Long Range Boiler Made Up of .094″ Thick Everdur Sheet, Automatically Metal Arc Welded — Tested to 300 Lb. Pressure

While the oxygen does little harm in the copper base metal, the oxygen-bearing copper wire cannot be used as a bare metal arc electrode. Not so much by reason of the small amounts carried in the original electrode, but rather by reason of the fact that in passing through the arc the oxygen content is increased to the point where the deposited metal is found seriously impaired in soundness, weak in tensile strength, and lacking in ductility.

Hence electrolytic or tough pitch copper is not recommended as a metal arc electrode.

Silicon.—The oxygen of electrolytic copper can readily be disposed of by remelting with an addition of some deoxidizing element, the most common of which are phosphorus, silicon, manganese, zinc and calcium boride. We then have *deoxidized copper.* Since it is not convenient to measure exactly the amount of oxygen in a bath of molten copper, a small excess of the deoxidizer is usually added to remain in the finished copper (except in the case of calcium boride).

For welding rods, a further addition of the deoxidizer is made in order to keep the copper free of oxygen in its passage through the arc. Silicon functions in this regard very effectively. It alloys with the copper, reducing all cuprous oxide to a composition of pure copper and silicon. The oxygen absorbed by the silicon forms therewith a silica glass which exists on the molten deoxidized copper as a thin film floating on the surface which further protects the molten metal from the oxygen of the air. In the case of Everdur, this action is exceptionally conspicuous, the molten metal being protected from oxygen attack in an arc blaze that would, for instance, be ruinous to steel.

Phosphorus.—This element is even more active than silicon in freeing molten copper of its oxygen content. It is also efficacious in protecting the copper metal as it passes through the arc. Thus we can obtain weld metal quite as sound and ductile as is the case with silicon deoxidized copper. The principal difference in the action of the two elements is that the phosphorus oxide does not form a film of glass on the surface of the molten copper, as is the case with silicon.

Zinc.—Though zinc is a rather powerful deoxidizer of copper, at temperatures around the melting point of the latter as in the high temperature of the arc, it vaporizes and burns with oxygen of the air to form the familiar white zinc oxide smoke or dust. Hence more of it is needed to protect the metal passing through the arc than in the case of phosphorus or silicon. On the other hand, if more than, say, 5 per cent is added, the zinc oxide is occluded in the weld metal, making the latter unsound and lacking in both strength and ductility.

For this reason, all of the brass rods, including even the familiar Tobin and manganese bronzes which work so admirably in the oxy-acetylene torch, are rejected as metal arc electrodes.

Manganese.—This element alloys as readily with copper as does any of the above. It does not, however, when acting alone protect the metal passing through the arc as effectively as either phosphorus or silicon. When in combination with silicon in the approximate ratio of 1:3, the resulting complex manganese oxide, silica glass is an even better protection to the molten metal than in the case of silicon acting alone.

In amounts totaling 4 per cent, as in Everdur, the manganese and silicon not only provide thorough deoxidation, but form with the copper a new, bronze-like alloy having nearly twice the strength in the weld metal of that of deoxidized copper.

Nickel.—Like manganese, nickel alloys with copper in all proportions. It is not, however, a deoxidizer, but improves the strength of the copper, though at a much slower rate than the silicon-manganese, and contributes toward improved corrosion resistance. With increasing amounts, it rapidly lightens the copper red until with 30 per cent we have the typical metal-white of nickel.

Since nickel does not react quickly with oxygen, it does not aid the copper in passing through the arc. Hence copper-nickel metal arc electrodes should carry an active deoxidizer which is usually manganese as in Ambrac and Monel metal.

Tin.—Tin, like nickel, is not a deoxidizer, but alloys with copper to make the familiar series of bronzes so highly prized for their beauty, strength, durability and wear resistance. While bronze was known and prized for its utility and beauty long before Abraham set his face west from Ur of the Chaldees, it was not until about 1860 that a Belgian chemist discovered the remarkable effect on the alloy of small amounts of phos-

phorus. Since that time, practically all of the tin bronzes have been deoxidized with phosphorus and have taken its name generally.

Tin is a metal of contrasts. Though it melts at a very low temperature, it will lie quiet at temperatures above that point where zinc has gone off in a cloud of vapor, and lead is boiling violently, while copper has melted and climbed to a dazzling white heat. Though it is one of the softest of metals, it increases the hardness of the copper alloy until in amounts of 20 per cent or more the alloy becomes one of the hardest of metals.

The phosphorus should be present in the alloy in amounts sufficient to protect both the tin and the copper as they pass through the arc. This being the case, we obtain a dense, strong weld metal which has particularly good wear resistance. The wear resistance increases with the tin content, the 10 per cent tin bronze being decidedly better in this respect than the 5 per cent bronze.

Variations in Compositions

It will be noted from the above that extremely minute quantities of one element or another make profound differences in the properties of the alloy. This is particularly true when the material is to be used for welding. It is not out of place, therefore, to point out to the welder that he should know something of the source of his material and the worth of the warranty behind it.

Typical Welding Problems

We can, of course, make a large number of combinations with the half dozen welding rods and the nine or ten base metals which we have quoted. However, as was stated earlier, it would be a waste of time if we did not touch on problems which you are likely to encounter in every-day work. With this in mind, we have done considerable work to prove the fitness or unsuitability of the metal arc process for a large number of copper alloy combinations.* These problems are of the nature stated below with an explanation of the measure of success one is likely to encounter in their solutions.

To metal arc weld electrolytic or tough pitch copper.—Practically all of the copper used in the electrical industry, wires, cables, bus bars, terminals, switches, etc., is of this high-purity oxygen-bearing variety. Likewise practically all of the sheet copper used for roofing, leader and gutter work, architectural and store front trim small articles and utensils is of the same variety.

Up to the present time nearly all of the industrial containers where copper was the accepted material such as varnish kettles, cannery, brewery and distiller equipment, hot water storage tanks, fire extinguishers, etc., have also been made of the oxygen-bearing copper. This last group is rapidly going over to deoxidized copper or one of the copper alloys by reason of the easier welding of the latter.

Difficulties

In tackling the problem of welding electrolytic copper, the operator is confronted with three difficulties which he does not encounter in the welding of steel or iron.

*Most of this work was done in collaboration with the Westinghouse E. & M. Company at their Welding Research Laboratory, East Pittsburgh, Pa. We are glad to acknowledge indebtedness to the Westinghouse Company and Mr. A. M. Candy of their General Engineering Dept. for his unflagging interest and Mr. C. E. Swift for his painstaking work on both the manual arc and automatic arc as well as the Westinghouse Physical Test Laboratory for numerous tests on welded samples.

Oxygen in Electrolytic Copper

The first of these arising from the weakening effect of the oxygen content is not serious and can be taken care of by allowing somewhat greater contact area than would normally be the case. The welding rod, as was pointed out above, must carry a deoxidizing element so that it is only necessary to provide protection to the relatively thin layer of the base metal on which the added metal will be deposited, thus preventing an increase in the oxygen content. A short distance back of the fusion zone, the cuprous oxide, which in wrought copper exists in the form of small particles and as such has no weakening effect on the metal as a whole, collects at the grain boundaries, causing a drop in the strength of the order of 10,000 lb. per sq. in. It is a simple matter to compensate for this weakening effect of the oxygen by using a wider angle V-groove, a shear "V" or a wider reinforcing bead than would be the case in steel.

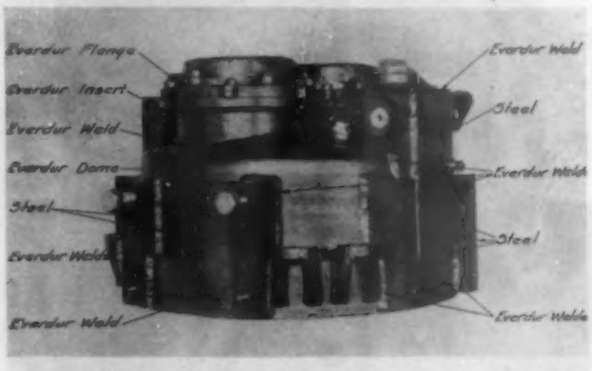


Fig. 2—Part of a High Tension Circuit Breaker Dome Made Up of Steel with Everdur Inserts to Break Up the Magnetic Flux. Note the seams Where Everdur Metal Arc Welding Rod Was Used to Join Everdur to Steel

The other two difficulties are inherent in the copper alloys and must be overcome in the welding operation itself, viz., the fluidity of the copper alloy metal arc weld metal and the high heat conductivity of the electrolytic copper base metal.

Fluidity of Copper Alloys

The electrical engineers tell us that the arc temperature is something over 6000 deg. F., no matter what metal is used as the electrode. The high fluidity of the copper alloys which melt at temperatures less than 2000 deg. F. is accounted for largely by this 4000 deg. F. excess temperature. In some respects this is an advantage, as it speeds up the welding operation and is a disadvantage only when it comes to overhead or vertical welding. Since most articles made of welded copper are small enough to be tilted at least to an angle of 45 deg., this fluidity of the copper alloys occasions very little trouble. When it becomes imperative to do vertical welding an ingenious welder can still accomplish this by working his electrode inside a movable crucible which retains the bead in shape until the metal solidifies. Overhead metal arc welding of copper alloys is at this writing regarded as impractical.

The only serious difficulty which the welder encounters in the joining of electrolytic or tough pitch copper is occasioned by its high heat conductivity. This property is, of course, a great advantage when we desire to use the copper in the form of a heat exchanger. In c.g.s. units it measures 0.92, which is eight times

the conductivity of the best grade of boiler steel. In general, it means that the metal arc cannot get the heat into the base metal fast enough to fuse it before the added metal comes down. The result is the same as the pouring of hot metal onto a cold plate—no weld. This means that in many cases preheating must be resorted to.

Solution of the Problem

The problem has two objectives. First, the obtaining of a permanent high electrical conductivity connection for bus bars, generator, motor and transformer and circuit-breaker connections and, second, the obtaining of a strong weld for fabricating containers, joining sheets, tubes and shapes.

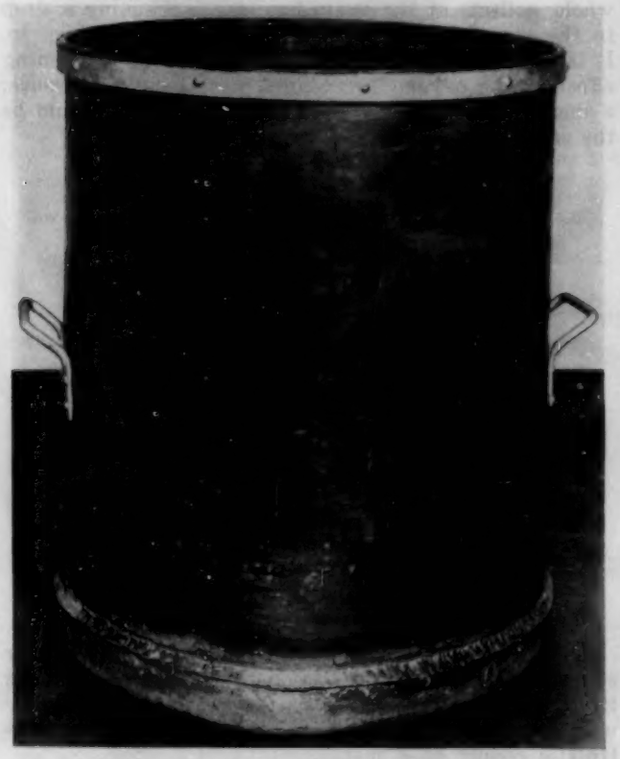


Fig. 3—Varnish Kettle 42" Diameter x 42" High Used for Boiling the Varnish Gum with the Oil in the Manufacturing Process. Made of Hot Rolled Everdur Sheet All Welded

High Electrical Conductivity Connections

For this purpose, repeated trials using 5/32 in. diameter deoxidized copper metal arc electrodes on ¼-in. thick electrolytic copper with current values up to 200 amperes brought out the fact that a red preheat was necessary to secure even indifferent adherence of the weld metal. On 1/16-in. thick copper base metal spaced 1/16 in. apart with 175 amperes on a ⅛-in. diameter, deoxidized copper electrode and no preheat, good welds were obtained, developing nearly the full strength of the base metal in its soft condition. In the latter case, the reinforcing bead was not machined off so that there would be ample metal to carry currents across the connection.

The general conclusion from the above is that metal arc welds in heavy copper conductors, such as heavy bus bars, is at present impractical and some other means of connection, such as bolted connections, silver soldered, brazed or butt welded connections, must be used. On the other hand, for copper thinner than, say, ⅛ in., satisfactory metal arc welds can be obtained by the use of heavy current densities of the order of 15,000* amperes per sq. in. without resorting to preheat.

High Strength Welds in Electrolytic Copper

For this purpose, we are not limited to a deoxidized copper electrode, but may select a phosphor bronze or Everdur electrode which yields a higher strength in the weld metal. However, we encounter the same difficulty by reason of the high thermal conductivity of the base metal, and as far as the metal arc is concerned we must conclude that it is impractical for thicknesses of the electrolytic copper base metal greater than, say, ⅛ in.

For the thinner gages, the metal arc may be employed, using an Everdur electrode and current densities of the order of 12,000 to 30,000* amperes per sq. in. But for all thicknesses, the more economical method of welding will be found in the carbon arc or the oxy-acetylene torch.

Heavier current densities can be used with the smaller rods than with the larger rods.

Deoxidized Copper—Strong Metal Arc Welds

In the use of deoxidized copper instead of electrolytic copper, one of the difficulties encountered in the latter is eliminated, i.e., the weakening effect of the cuprous oxide, and the other, the high thermal conductivity, is somewhat diminished. Both the electrical and thermal conductivities drop off rather rapidly with additions of the deoxidizing elements. The thermal conductivity of deoxodized copper will vary, but in general it will probably be found between 0.4 and 0.8 cal/cm³/cm/sec/Deg. C. Thus it is still from three to seven times that of steel and will require considerably more heat for this reason.

Results on deoxidized copper:—One trial where 150 amperes on a 5/32" diameter Everdur metal arc electrode and a dull red preheat in the ¼" thick deoxidized copper sheet was found to yield only mediocre strength of the order of 20000 lbs. per sq. in. due to poor fusion.

Another trial using the same values with 5/32" diameter phosphor bronze electrode yielded even lower strength.

Still further trials using the automatically controlled arc with the 5/32" diameter phosphor bronze electrode and current values up to 350 amperes without preheat brought out the fact that the heavier current would give fair penetration and strength but were impracticable on account of the unsoundness of the weld metal.

With 1/16" thick deoxidized copper sheet, no preheat, and ⅛" diameter Everdur electrode carrying 125 amperes or ⅛" diameter phosphor bronze electrode with 100 amperes, there was no difficulty in developing the full strength of the base metal.

The general conclusion from the above tests would be that deoxidized copper, like electrolytic copper, can not be economically welded by the metal arc process in thicknesses greater than approximately ⅛" but in thicknesses less than this, it can readily be welded by Everdur or phosphor bronze electrodes.

It would follow from the above that a deoxidized copper electrode could also be used but is not recom-

*Current densities on various welding rods compared with the current in amperes are as follows:

Size Rod, In.	⅛ In. Diameter			5/32 In. Diameter			3/16 In. Diameter	
Amperes	123	184	368	192	240	288	276	345
Amperes per sq. in.	10,000	15,000	30,000	10,000	12,500	15,000	10,000	12,500

mended on account of the lower strength of the weld metal itself.

Metal Arc Welding of Brass

While the heat conductivity of brass is decidedly lower than electrolytic copper and appreciably lower than deoxidized copper as well, it is still high enough to be a handicap to the welder. In c.g.s. units, it varies from 0.29 for Muntz Metal to 0.45 for commercial bronze, increasing with the copper content of the brass.

Again since one end of the metal arc springs from the base metal, we encounter further difficulty from the volatilization of the zinc. These two handicaps call for opposite treatments, higher heat in the arc to compensate for the high thermal conductivity of the base metal and lower arc heat to avoid too great a loss of zinc. Obviously, both conditions can not be met so that a compromise is necessary.

Extensive tests have brought out the following points:

(1) There is not at the present time a metal arc electrode which will give a good color match with the yellow brasses. Phosphor bronze or Everdur will yield a reasonably good color match to commercial bronze and to a less extent to red brass.

(2) The two metal arc electrodes found most satisfactory are Everdur and Phosphor Bronze. Of these two electrodes, the Everdur will stand more heat and still yield sound weld metal than the Phosphor Bronze which is apt to come down porous with excess heat. The Everdur weld metal will have partly inherently and partly for the above reason greater strength than the Phosphor Bronze weld metal. On the other hand, Phosphor Bronze alloys with the brasses more avidly than the Everdur.

(3) It is not practicable to weld commercial bronze or 85:15 red brass in thicknesses greater than approximately ⅛" by the metal arc process without a certain degree of preheat.

With the thicknesses less than ⅛", the full strength of the commercial bronze or 85:15 red brass is obtained without difficulty. Thus with ⅛" diameter electrodes in Everdur and Phosphor Bronze with 140 amperes with the former and 110 amperes with the latter, the full strength of 1/16" thick commercial bronze or 85:15 red brass is obtained. Similar results were obtained with the automatic arc using ⅛" Everdur wire except that the heat (amperes) had to be increased in order to compensate for the more rapid progress of the weld.

There was no appreciable loss of zinc in the welds on the 1/16" thick commercial bronze or 85:15 red brass.

(4) With the higher zinc brasses (30% to 40% zinc) the heat conductivity, though still several times that of steel, is sufficiently low so that preheat is not necessary. On the other hand, the difficulty on account of the burning of the zinc has increased to such proportions as to make the weld weak and unsound. This is true no matter whether the material be thick or thin.

As a general conclusion, therefore, it would seem that metal arc welding on the high zinc brasses is impracticable. That does not mean that some ingenious welder can not succeed in making satisfactory metal arc welds but the investigation has been sufficiently thorough to point to the use of the carbon arc or the oxy-acetylene torch as being the more economical method of welding. The carbon arc method of welding high zinc brass has not been thoroughly worked out but one series of welds using the carbon arc, 90 amperes, and ⅛" diameter Everdur filler rod on 1/16" thick common brass developed 44,000 lb. per sq. in. or approximately the full strength of the soft brass.

The problem of welding extruded brass is somewhat similar to that of welding Muntz metal. The various welding methods for welding extruded architectural shapes of brass and bronze is being dealt with in another paper.

Phosphor Bronze—Metal Arc Welds

There is perhaps no pressing problem in the metal arc welding of Phosphor Bronze sheet as there is in the welding of copper sheet and only a casual survey has been made. However, we run into no serious difficulties in making metal arc welds on this material. The heat conductivity is low and there is no highly volatile element like zinc to give the operator trouble. Using a Phosphor Bronze metal arc electrode, and only sufficient heat to secure proper fusion of the base metal, good welds are readily obtainable. The one precaution that the welder must observe is that the metal must not be put under strain while still red hot as otherwise cracks are likely to open up due to red shortness in the metal.

Fig. 4—Steam Jacketed Chemical Vat Used in the Die Industry Made Up of All-Welded Everdur Sheet. Note Steel Angles Welded Directly to the Everdur Vat

Ambrac, etc.—Metal Arc Welding

There is a growing demand for a rustless, corrosion-resisting white metal for metal doors, window frames and sash, grill work and architectural trim. Such a metal in the form of nickel silver and Ambrac has long been used for kitchen equipment in hotels, restaurants, and the larger residences and apartments. The nickel silvers with a zinc content of 15% to 25% are somewhat difficult to metal arc weld by reason of the zinc content though we are not handicapped as in the case of the brasses by a high heat conductivity.

It is entirely possible to metal arc weld nickel silver

using a phosphor bronze, Everdur or Ambrac electrode. The weld is not as likely to be as free from porosity as would be the case if a carbon arc or the oxy-acetylene torch were used. Hence this method is not recommended for welding unless the weld can be left reinforced in the back of the finished article. The Ambrac is the only available welding electrode that will make a good color match with the nickel silver base metal.

For the above reasons, where the metal arc is to be the method of connection, Ambrac is to be preferred for both base metal and welding electrode. The following results indicate approximately what can be expected of metal arc welding on Ambrac sheet using Ambrac welding electrodes.

(a) 1/16-in. thick Ambrac sheet, ⅛-in. diameter Ambrac electrode, automatic arc of 80 amperes at 15 in. per minute along seam. Tensile strength developed by the reinforced weld of 34,000 lb. per sq. in. With the weld filed flush about two-thirds of this strength is developed.

(b) ⅛-in. thick Ambrac sheet, 5/32-in. diameter Ambrac electrode, 220 amperes automatic arc, 12 in. per minute of arc along seam. Tensile strength developed by the reinforced weld was 32,000 lb. per sq. in., while that developed by the same weld filed flush averaged 22,000 lb. per sq. in.

The above results, while developing a considerable proportion of the strength of the base metal, can undoubtedly be improved by a suitable fluxing of the weld metal. In this case only a light sprinkling of fused borax plus 10 per cent sodium fluoride was used. The electrode was bare.

Everdur—Metal Arc Welds

By far the most weldable of any copper alloy is Everdur. With a tensile strength in the dead soft condition equivalent to the usual boiler plate steel, a ductility as measured by the elongation, comparable to that of the best Swedish iron; entirely non-magnetic; thermal conductivity even lower than steel; better non-corrosiveness than copper and the self-fluxing properties of wrought iron, industry finds in Everdur an admirable metal for a multiplicity of uses. As was noted in the case of phosphor bronze, the only precaution the welder must take is that of avoiding too great a tensile stress on the weld in the brief interval when it is red hot.

The following values are typical of the results obtainable:

Type 14325:—Normally all plates greater in thickness than ⅛ in. would be beveled before welding. But in this test made on ¼-in. Everdur plate, the best metal was left with a square sheared edge and spaced 3/16 in., the object being to demonstrate the maximum penetration obtainable, using unusually heavy currents for the purpose. 3/16-in. diameter Everdur electrode, 300 amperes, hand operated, no preheat.

The welds were machined flush and tested with maximum and minimum values of 50,100 and 39,800 lb. per sq. in., with an average of 42,260 lb. per sq. in. and 16.6 per cent elongation in 2 in.

Somewhat better results could undoubtedly have been obtained with beveled edges. Less than 1/16-in. reinforcement would have developed the full strength of the plate.

Test 14340:—¼-in. thick beveled edge Everdur plate welded with the *automatic arc* at 15 in. per minute travel of arc along seams, 300 amperes on 5/32 in. diameter Everdur wire which melted at rate of 43.7 in. per minute (approximately 3 in. of wire per inch of seam). Weld machined flush with sheet.

An average tensile strength of 42,170 lb. per sq. in., with 14.7 per cent elongation in 2 in. was obtained on a series of six test specimens.

It is probable that a 3/16-in. diameter electrode would have resulted in an improvement. 300 amperes on a 5/32-in. diameter electrode means a current density of 15,700 amperes per sq. in., which is quite high even for Everdur.

Test 10507*:—0.118-in. thick Everdur sheet welded with ⅛-in. diameter Everdur wire at 130 amperes at 13 in. per minute travel along seam, 0.085 in. reinforcement above sheet. Average of seven tensile sheets showed 52,700 lb. per sq. in. with 25.1 per cent elongation in 2 in.

Test 14328:—Everdur sheet 1/16 in. thick, ⅛-in. diameter Everdur electrode, hand-operated with 60 amperes, which was too low for smooth action, but which yielded sound welds. Reinforcing bead 0.08 in. high. Average tensile strength 53,500 lb. per sq. in. with 45.7 per cent elongation in 2 in.

Test 14330 *and* 14332:—With the *automatic arc* made on 1/16-in. thick Everdur sheet we were able to secure very high welding speeds with excellent results. With the sheets spaced 1/32 in. apart and ⅛-in. diameter Everdur wire at 150 amperes and a travel of 15 *in. per minute* along seam, we obtained 50,970 lb. per sq. in. with 22.5 per cent elongation in 2 in. as an average of seven tests. The reinforcement averaged 0.082 in. above the plate.

With the travel stepped up to 24 in. per minute along weld and all other conditions the same, the average strength was 52,600 lb. per sq. in. with 36.4 per cent elongation in 2 in. with a reinforcement of 0.062 in. above the sheet.

With Everdur sheets thinner than 1/16 in., the carbon arc or the oxy-acetylene torch will probably prove to be the most efficient.

Test 19540†:—An actual example or carbon arc welding in 0.04-in. thick Everdur sheet. In this case no filler rod was used, but one edge of the 0.040-in. thick sheet was bent up ⅜ in. to an angle of 45 deg. and the other edge slipped under this projection. With 180 amperes in a short arc, the seam was welded at 24 in. per minute.

The reinforcement averaged 0.059 in., while the average tensile strength was 68,500 lb. per sq. in. with 6.6 per cent elongation. The high tensile strength and low elongation in this instance was due to cold rolling effect in the original sheet. Normally, we would not expect over 55,000 lb. per sq. in. in welded Everdur sheet, but the elongation would be much higher than the above value.

Everdur on Steel

While we have no tensile tests to demonstrate the value of the welded connection Everdur to steel using an Everdur metal arc electrode, some recent work involving the welding of non-magnetic Everdur panels in sheet steel transformer tanks has demonstrated an excellent value for such a weld, probably of the order of 40,000 lb. per sq. in. or better.

While this paper deals almost entirely with metal arc welding, it is not out of place to point out that there are many cases where the carbon arc process, the oxy-acetylene torch, seam or butt welding would be the optimum process to use. Thus we have demon-

*Made on General Electric automatic arc welder.
†Run on an automatic carbon arc welder.

strated here in the ineffectiveness of the metal arc or the thicker sections of electrolytic copper, deoxidized copper and brass. Where the difficulty is due to the high heat conductivity of the material the oxy-acetylene torch with its steady, intensely hot inner cone and the preheating effect of the spent gases would work admirably, yielding strong, sound welds. Or the carbon arc with a fatter blaze and better heat control than we can get with the metal arc may work equally well.

Where the difficulty is occasioned by the vaporization of the zinc, the neutral flame of the oxy-acetylene torch gives protection as well as heat or the carbon arc with the arc springing from a non-zinc weld metal such as phosphor bronze or Everdur can be applied.

Again with metal thinner than approximately 1/16 in., the carbon arc, the oxy-acetylene torch or the seam welder can usually be applied.

SUMMARY

Thus as far as the metal arc process is concerned, we have demonstrated the following points:

(1) On electrolytic copper of say 1/32 in. to 1/8 in. in thickness, sound, high conductivity welds can be made with a deoxidized copper electrode. A stronger weld can be made using an Everdur or Phosphor Bronze electrode.

For electrolytic copper thicker than approximately ⅛ in., metal arc welding without preheat is impractical.

(2) On deoxidized copper base metal, a similar result is obtained.

(3) On the low zinc brasses such as commercial bronze and 85:15 red brass, a like result is obtained owing to their similarity to copper as far as heat conductivity is concerned.

(4) With the high zinc brasses such as common brass and Muntz metal, zinc volatilization takes place to such an extent as to render this process impractical.

(5) Phosphor bronze is readily metal arc welded using a Phosphor Bronze electrode though we do not get as sound a weld as in the case of Everdur on Everdur.

(6) Ambrac is also readily metal arc welded using an Ambrac electrode. Like Phosphor Bronze, we need a certain amount of reenforcement to make up for a slight lack of soundness. It is probable that the carbon arc or the oxy-acetylene torch will be found the optimum for most jobs.

(7) Everdur is without doubt the most easily welded of the copper alloys, and we obtain with it the highest strength and soundness. It is unimpaired by the intense heat of the metal arc and only a slight reenforcement is necessary to develop the full strength of the base metal.

Ornamental Iron Work in Demand

By **R. W. BOGGS**

✦ Mr. Boggs is a Mechanical Engineer with the Union Carbide Company.

APPLICATIONS of the oxy-acetylene process embrace a wide range of work. The contract welder has found that his services are in demand not only for the reclamation and repair of broken parts and worn out machinery but also for directly productive, creative work. Through the increased knowledge of the public concerning the application of the oxy-acetylene process the well-equipped and suitably situated welding shop has found keeping up with orders the main difficulty.

The development of the demand for modernistic metal furniture and other objects for the house and garden has opened up a lucrative field for shops that do ornamental iron work.

The new designs lend themselves admirably to fabrication by the oxy-acetylene process. The result has been that many shops favorably situated have taken advantage of this trend of fashion to expand their business greatly.

One welding shop in western New York began a short time ago to fabricate ornamental iron objects as a side line. The result of their efforts has been to develop a very profitable demand for such objects. A typical example of their work is shown in Fig. 1. This andiron is 36 in. long and 18 in. high. It was designed for a sun porch having a tile floor, where no screen would be needed. The design without the flowers and leaves is made up of three variations of a single scroll form. All of the metal used is hand wrought with the aid of the oxy-acetylene flame, and the joints are all welded. In making the flowers the designs are first cut with the cutting blowpipe and then heated locally with the flame of the welding blowpipe so that they can be hammered easily into shape. The effect of the blowpipe flame considerably enhances the appearance of the iron by giving it a look of real antiquity.

In Fig. 2 are seen coffee tables of hand wrought iron with tops of black glass. All of the work shown in the two illustrations was done by the oxy-acetylene process. It can be seen from these illustrations that the quality of ornamental iron work produced today is superior to the genuine antique not only in strength but also in appearance. The crude appearance of antique wrought iron was caused by limitations placed upon the artist or worker by the methods that were available at that time rather than by the desire of the artist to create an impression. The speed and simplicity with which this work is done today in no way lessens the artistic merit of the finished product.

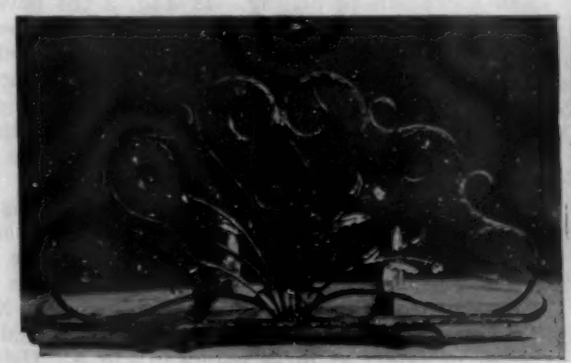


Fig. 1—A New Idea in Andirons

Fig. 2—Nest of Tables Fabricated by the Oxy-Acetylene Blowpipe

Welded Machinery Foundations for Ships

By G. H. MOORE, JR.

✦ This paper is to be presented at the Annual Meeting of the A. W. S., April, 1931, by G. H. Moore, Jr., of the Newport News Shipbuilding and Dry Dock Co.

FOR the past three or four years the Newport News Shipbuilding and Dry Dock Company has done considerable welding of machinery foundations in a number of ships. Their practice has covered the field generally from large boiler foundations, where strength and the tying to the main hull structure are of vital importance, to the foundations for small pumps or other auxiliaries which are merely seatings or stools. No main engine foundations have yet been attempted which is not because they feel that such foundations could not be satisfactorily designed and built but because they feel that, in this very important departure from the long continued practice of riveting it is best to proceed slowly.

The Newport News Shipbuilding and Dry Dock Company have found that welded foundations effect savings in weight and cost and that the erection is simpler and easier.

It is intended in this brief paper to convey some general ideas and standard details which have proved practical on a number of ships. While there is much that could not be included, it is hoped that the data presented will prove of value especially to those who are welding auxiliary foundations for the first time.

General Considerations

The riveted foundation is designed principally from precedent and rule-of-thumb and much depends on the judgment of the designer. The same methods and empirical rules may be used for welded foundations where a surprisingly simpler design is inherently possible with fewer parts, requiring less time and effort on the part of the designer and ship fitters. The majority of foundations are directly under the machine, or tank, and act in part as a column. In other cases the beam, or girder, is the outstanding feature. These fundamentals are dictated by the proposed location and its relation to bulkheads, tank top, deck and other parts of the ship and machinery. The shape and nature of the machine must also be considered and rotating and reciprocating motions have to be taken care of as well as static loads, and stresses due to inertia. Each foundation is a problem of its own, but simplicity is possible when welding is used.

Rolling and pitching of the ship in a heavy seaway will highly stress the foundation, due principally to the weight of the machine. Collision may cause failure by shearing the bolts, thus breaking high pressure pipe joints, or it may cause buckling of the foundation structure.

The ship's structure, to which the foundation is attached, plays a considerable part in the effectiveness of the design. When the foundation is on the inner-bottom (tank top) the floors and longitudinal help to distribute the localized stresses. On a deck, the beams, deck girders, pillars (column) and brackets, as well as bulkheads, may be used to advantage, but when attached to a bulkhead, or pillar, a cantilever condition producing serious bending moments is sometimes met with. Local strengthening of the members to which the foundation is attached must be considered.

The designs shown in Figs. 1, 2 and 3 are examples of foundations which have proved successful in practice.

Economies

It is proved in practice that drafting time is reduced and drawings are simpler. When the power plant is being laid out and machine locations determined it is unnecessary to arrange the parts so that existing rivet holes will line up with the foundation members.

Material is saved by eliminating the parts used only for connections and the remaining material is placed to better advantage.

Usually the main structure is well advanced before the details of the machinery are sufficiently settled to permit designing of the foundations. They may be designed later as units, thus simplifying the work of the draftsman, loftsman, fabricator and fitter.

Mold loft work is reduced in two ways. Templates for the structure to which the foundation is attached do not have to be reworked in order to show rivet holes, nor is it necessary to show the welded joint connections.

When erection on the shipways is under way, main structural parts are erected, bolted and riveted to better advantage, if the minor parts are eliminated for later consideration.

When the foundation is located and leveled, welded connections do not require the consideration that a riveted job does. As there are no rivets to the adjoining structure the possibility of leakage is reduced.

Strength of Welded Joints

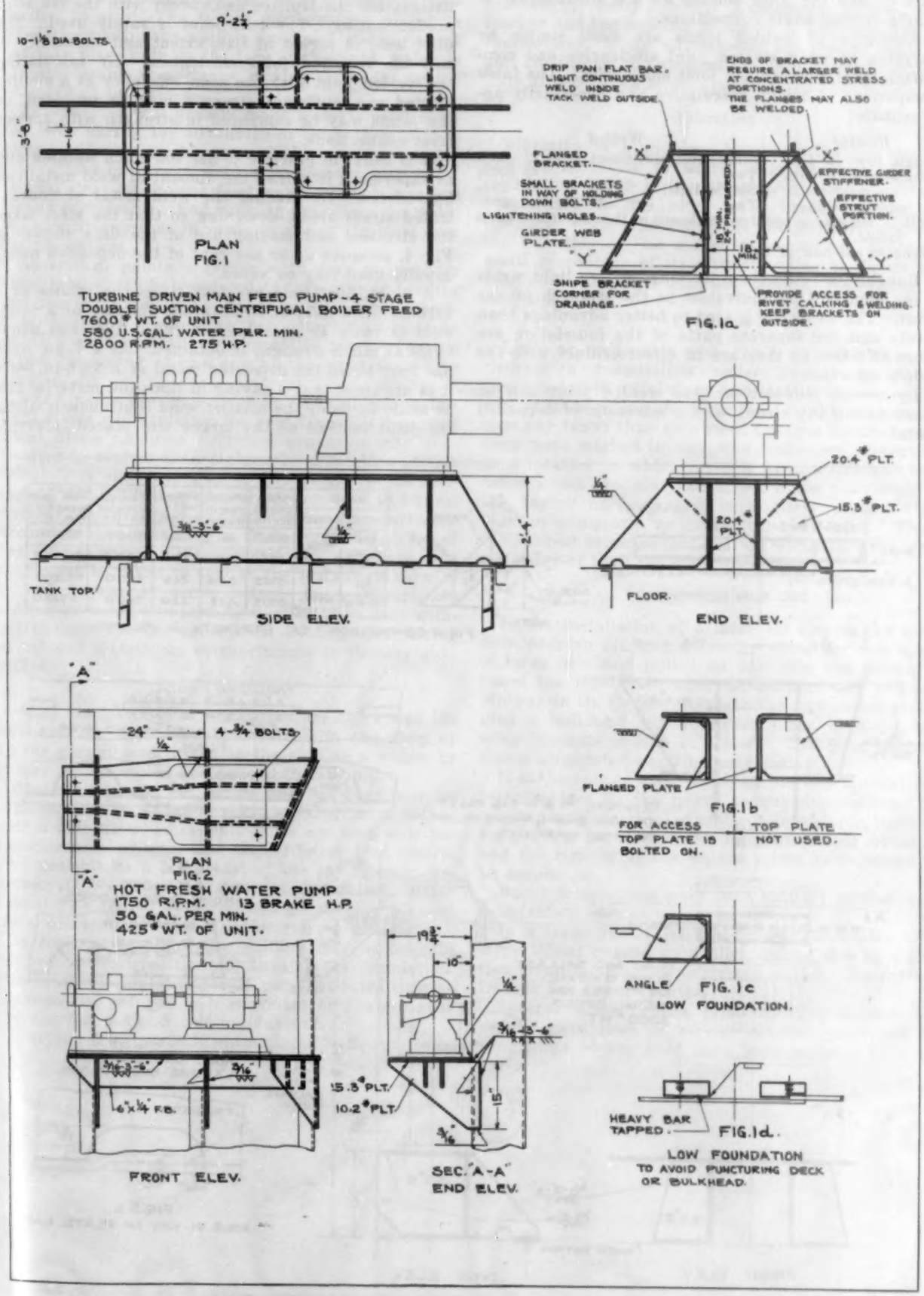
Considerable thought and study has been applied to this subject by the advocates of welding, the result mainly sought being strength and rigidity.

My object is to present successfully tried empirical rules. If the data available to the draftsman is simple he will use it, otherwise it confuses his thoughts. The welder should receive his information from the plans and not have to guess at what is required.

The girder principle in Fig. 1 is simple and safe. With a cantilever condition, as in Fig. 2, the critical point is where the top plate joins the stiffener, or if on the other side of the bulkhead, where it would join the bulkhead plating. In Fig. 3 the lower part is subject mainly to crushing and the bulkhead has been stiffened locally to take care of the top bolts. If the bulkhead in Fig. 3 had this machine attached wholly to it, instead of partly to the tank top, then a serious condition would occur if the compartment is flooded. The localized weight added to the water pressure would cause severe local stresses.

Brackets should be located near the holding down bolts when possible and carried to some member capable of taking the stresses during service.

The sheer value of the bolts is a good index to the strength of the welds used in the planes "X-X" and "Y-Y" in Fig. 1a, as these welds have a considerable factor of safety at these points in Fig. 1. Using the ultimate shearing value of the bolts, the welds at


9'-2¼"
10-1⅛ DIA. BOLTS
PLAN
FIG. 1
TURBINE DRIVEN MAIN FEED PUMP - 4 STAGE
DOUBLE SUCTION CENTRIFUGAL BOILER FEED
7600 # WT. OF UNIT
580 U.S.GAL. WATER PER. MIN.
2800 R.P.M. 275 H.P.
DRIP PAN FLAT BAR. LIGHT CONTINUOUS WELD INSIDE TACK WELD OUTSIDE.
ENDS OF BRACKET MAY REQUIRE A LARGER WELD AT CONCENTRATED STRESS PORTIONS. THE FLANGES MAY ALSO BE WELDED.
FLANGED BRACKET.
SMALL BRACKETS IN WAY OF HOLDING DOWN BOLTS.
LIGHTENING HOLES.
GIRDER WEB PLATE.
EFFECTIVE GIRDER STIFFENER.
EFFECTIVE STRUT PORTION.
SNIPE BRACKET CORNER FOR DRAINAGE.
PROVIDE ACCESS FOR RIVET CALKING & WELDING. KEEP BRACKETS ON OUTSIDE.
FIG. 1a
TANK TOP.
SIDE ELEV.
20.4# PLT.
15.3# PLT.
FLOOR.
END ELEV.
"A"
24"
4-¾" BOLTS
PLAN
FIG. 2
HOT FRESH WATER PUMP
1750 R.P.M. 13 BRAKE H.P.
50 GAL. PER MIN.
425# WT. OF UNIT.
6"x¼" F.B.
FRONT ELEV.
19¾"
10"
15.3# PLT.
10.2# PLT.
SEC. "A-A"
END ELEV.
FLANGED PLATE
FIG. 1b
FOR ACCESS TOP PLATE IS BOLTED ON.
TOP PLATE NOT USED.
ANGLE
FIG. 1c
LOW FOUNDATION.
HEAVY BAR TAPPED.
FIG. 1d.
LOW FOUNDATION
TO AVOID PUNCTURING DECK OR BULKHEAD.

"X-X" and "Y-Y" have a factor of safety of 6 and 9 respectively. The unknown factors are amply taken care of and the joint efficiencies are about equal to single riveted angle connections.

Strengths of welded joints are made simple by carrying in mind riveted joint efficiencies and comparing them with welded joint efficiencies. The table comparison is briefly descriptive and necessarily approximate:

Riveted		*Welded*	
Single row	= 45%	Single full continuous weld	= 50%
Double row	= 65%	Two " " "	= 100%
		Single light " "	= 25%
		Two " " "	= 50%

Full = leg size is equal to thickness of thinner of the parts joined.
Light = one-half of full.

Roughly, a full weld 3 in. long, or two light welds 3 in. long, will be equivalent to the strength of one rivet. The welds are placed to better advantage than rivets and the separate parts of the foundation are more effective as they are in direct contact with the ship's structure.

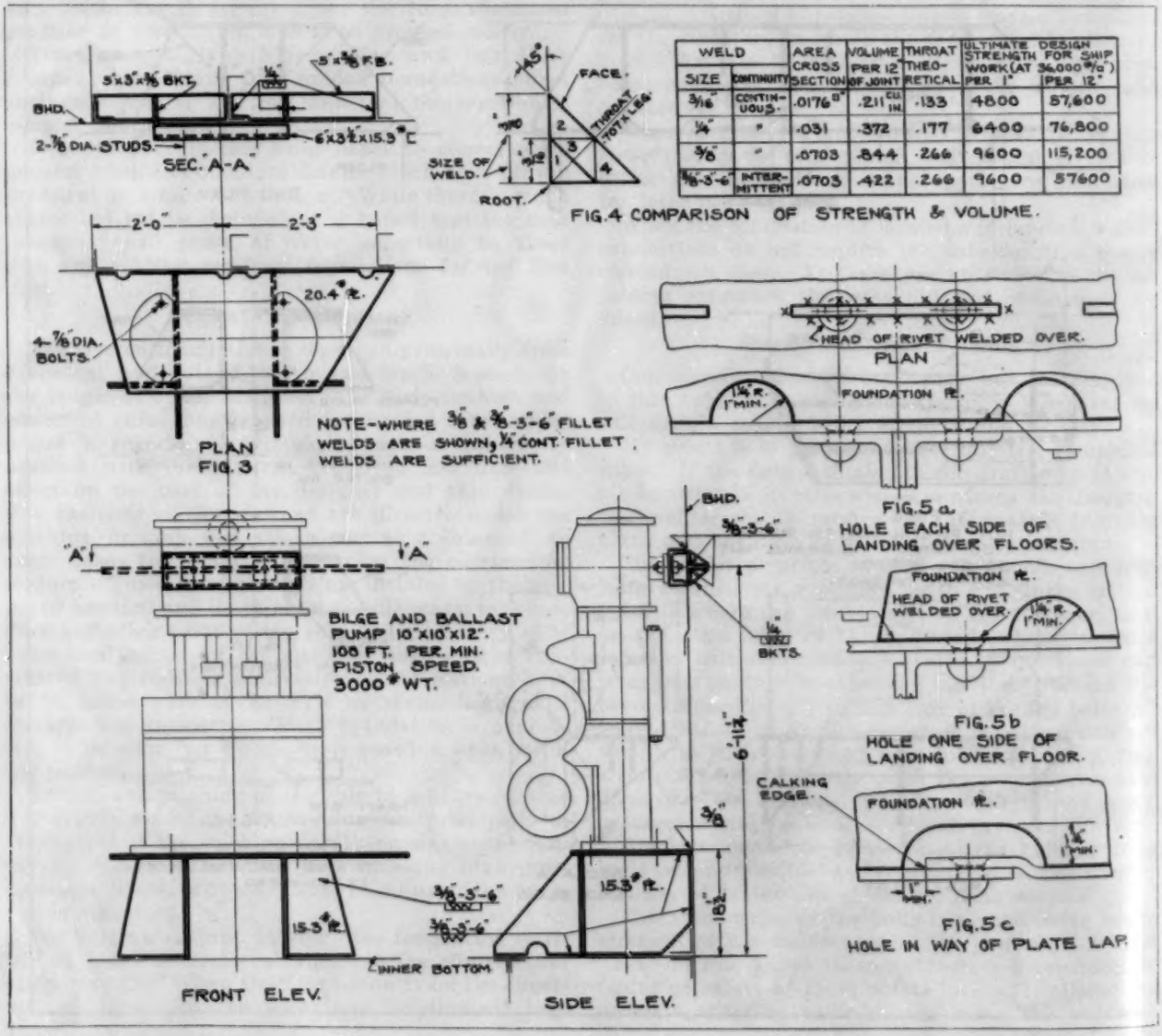
By proper calculations, the welded joint can be made sufficiently strong with a minimum of deposited metal.

Design

The usual forms of joints used in machinery foundations are the lap, tee and corner with the tee joint predominating. The butt joint is rarely used. The fillet weld is varied in size, extent and continuity to suit the required joint efficiencies. By calculating the welded joint with the same efficiency as a similar riveted one, sufficient strength may be provided, or the joints may be compared in strength with former rivet connections.

It is usual in practice to use too much welding and as experience is gained the amount of weld metal can be reduced. By placing the weld metal at concentrated stress areas, designing so that the steel takes the stresses, and making use of the data shown in Fig. 4, as much as 50 per cent of the deposited metal usually used may be saved.

A ⅜-in. fillet weld has four times the volume of a 3/16-in. fillet weld and the throat distance of a ⅜-in. weld is twice as great as a 3/16-in. fillet and about twice as much strength is obtained. As a ⅜-in. weld has four times the deposited metal of a 3/16-in. weld it is apparent that a saving in time and material can be made by using the smaller weld continuously along the joint instead of the larger size placed intermit-



tently. This is apparent from Fig. 4. A small continuous weld is as effective as a larger intermittent one, and there is evidence that it is stronger in proportion to size. The faying surfaces are sealed in when the continuous weld is employed and corrosion can take place only on the face of the weld, which is of considerable importance in ship work due to the presence of salt water.

As a welder will usually make a small weld oversize, only part of the advantage of using them is thus gained. However, for practical purposes, many foundations have been welded throughout with ¼-in. (actual size) continuous fillet welds and this size has proved serviceable. Bad working conditions for welding usually cause an increase in size of the weld over the theoretical.

At critical points a larger weld may be used or other means may be developed to take care of bending and tearing conditions. Progressive shear is sometimes found in brackets at their attachment to bulkheads when the cantilever moment is great. Tearing action beginning at one end of the weld should be avoided.

When welds are made over or near oil and watertight rivets and caulking, the heat from the deposited metal often produces sufficient expansion and contraction to destroy their tightness. Some idea of this principle is shown in Fig. 5. Where the welds completely seal the faying edge or surface of a structural member the advantage of protection against corrosion occurring simultaneously at both the heel and toe of the weld is gained. When continuous welds are used care must be taken to seal in the leakage, otherwise it will appear at some distant point. Completely sealing by welds also permits riveting to be done without thought for the subsequent welding and testing of oil and watertight compartments is thereby simplified.

Shop Conditions

After the parts of a foundation are fabricated the unit may be assembled and welded in the shop or on the ground and placed in the ship as a whole, or it may be assembled and welded in the ship.

Sheared and gas cut plates and flat bars may be tack welded by an apprentice working as a helper with a ship fitter. Assembly holes are used only for exceptional conditions and should be avoided wherever possible as a large part of the saving may disappear if holes must be laid off and punched. After assembly, a skilled welder completes the job. Manual metal arc welding is used exclusively on foundations.

In some cases all of the welding may be done in flat and vertical positions by turning the foundation. Overhead welding requires 25 per cent more time so it should be reduced to a minimum by the designer and the flat position welding favored.

Warping is not usually encountered in foundations, but it may be prevented by using small welds, with larger welds at the concentrated stress areas, and by brackets properly placed. Experience is the best teacher and the problem is simple in the usual run of foundations. Minor adjustments are readily made to suit conditions as found on the ship during erection. This kind of work is popular with the ship fitter.

Vibration

Vibration is a problem involving the foundation and the structure to which it is attached. In the foundation itself it is not as troublesome as that transmitted to the ship as a bracket welded at the point of greatest amplitude will usually damp out the vibrations. The welded joints do not slip at a small percentage of its ultimate value as do riveted joints. A properly designed welded foundation is stiff and rigid.

Corrosion

Little or no trouble with rapid corrosion is experienced in foundations under normal conditions. Deposited weld metal from bare low carbon electrodes will, if made with a short arc from good wire, not corrode any faster than ship steel. Covered electrodes are even more marked in corrosion resistance properties. In a location in which there is heat, water and coal ashes a bad condition exists, but if the weld seals in the faying surfaces and is properly protected by paint or bitumastic, no trouble need be feared. There is no direct evidence that fuel oil will attack the weld metal faster than the plate material.

Applications

In the installation of a large air compressor on a deck over an oil tank excessive vibration developed. A large belt and pulley on one side was found to cause the trouble because the motion was vertical. Midway in its 15 feet of length the foundation straddled a bulkhead located beneath the deck. Large wing brackets welded in place to distribute the end forces eliminated any further vibration.

It is the rule to make amply strong the foundations for machines having heavy reciprocating parts. In a few instances the foundations looked too light in weight but in service the location of the brackets and the rigidity of the welded joints have proved to be ample.

Boiler foundations have been entirely welded with satisfactory results.

In a large repair job the foundation angles of a large Diesel engine were fillet welded due to vibration loosening the double riveted angles. No further trouble has been reported.

Several ships whose auxiliary foundations are welded have been in service several years and no complaints of any kind have been made.

Tender Underframes Lengthened by Welding

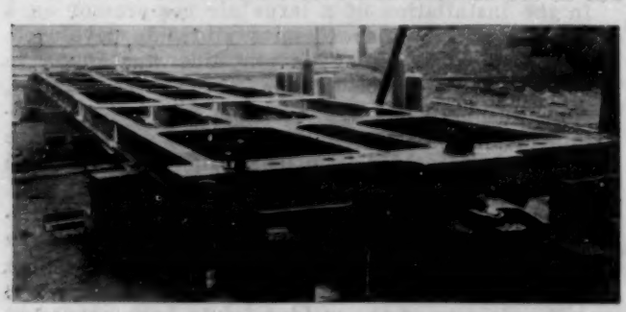
By E. V. DAVID

✦ This paper was presented before the New York Section of the American Welding Society on February 24, 1931, by E. V. David, Air Reduction Sales Company, Applied Engineering Department.

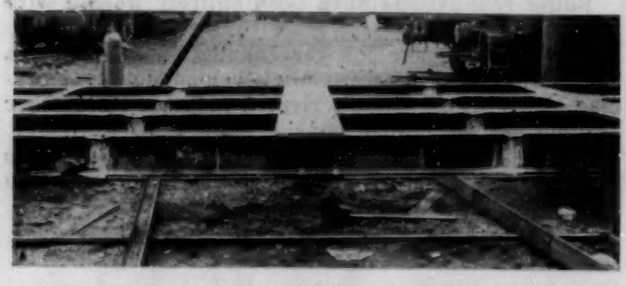
TO obtain tenders of increased capacity, demanded by the adoption of locomotives to longer runs and heavier trains, the Nickel Plate recently lengthened nine tender underframes and the tender tanks. It was desired to place the locomotives to which these tenders belonged on non-stop freight hauls between Conneaut, Ohio, and Buffalo, New York, and also between Conneaut and Bellevue, Ohio. The coal capacity of the tenders was already ample for the longer runs, but it was necessary to increase the water capacity. Estimates showed that the tanks would have to be lengthened by 8 ft.

Accordingly, the tanks were removed from tenders and cut in two with the oxy-acetylene torch at a predetermined point. The two sections were then separated 8 ft. apart and trammed in alinement. Plates 8 ft. in width with suitable stiffeners were inserted in the gap and riveted and welded in place, thus completing this part of the job.

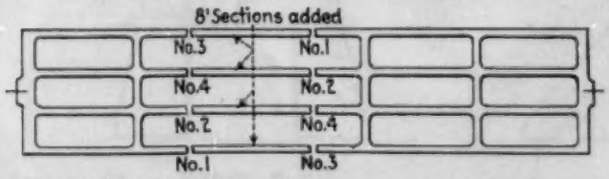
The one-piece cast-steel tender underframes were removed from the tender trucks and likewise cut in two with the oxy-acetylene torch at a suitable location. This entailed cutting of four longitudinal members of each underframe, each of I-beam cross section. Next, the two sections of underframes were separated 8 ft., blocked up about 3 ft. above the ground, trammed and brought into correct alinement with each other.



One of the Tender Underframes After Being Lengthened by Welding in Four I-Beam Sections



A Close-Up of the Sections Added to the Underframe and the Tie-Plate Riveted Across the Centers of the Inserted Sections



The Location of the I-Beam Sections Added and the Sequence of the Weld Made

Cast-steel I-beams 8 ft. long, 12 in. deep and with the same cross section as underframe members, were placed in the gaps, held in place by clamps and oxy-acetylene welded at both ends to the tender underframe.

The appearance of an underframe, after the welding was completed, is shown in one of the illustrations. The 8-ft. section inserted in each of the four longitudinal members, required a total of 8 welds per underframe. A close-up of sections added to the underframe is also illustrated. The points at which welds were made have been chalked to make them stand out more clearly. To further strengthen the underframe, tie-plates were riveted across the centers of the inserted sections.

In the welding procedure followed, due allowance was made for expansion and contraction in order to preserve the proper alinement of the underframe. The drawing show the order in which the welds were made. Four welders were actually working at the same time. After clamping the 8-ft. sections in place, two welders started work at each point designated as No. 1, and completed these two welds first. Next, the welds at each of the points marked No. 2 were completed by two welders.

Up to this juncture no tie-in welds had been made. The first tie-in welds which joined the two sections of the underframe together were the two designated as No. 3, which were completed next, each by two welders.

After finishing the two No. 3 welds, it was found that the frame had contracted together so closely at the two No. 4 points that it was necessary to build a charcoal fire around each No. 3 weld in order to give the expansion required at the No. 4 points before proceeding with these welds. Sheet asbestos and fire bricks were used to protect the welders from the heat of the fires. The two No. 4 welds were then completed without difficulty.

On the following day, charcoal fires were built around each of the eight welds and they were heated simultaneously to a cherry red to relieve and equalize any strains which might have been set up. The welding time per underframe per welder averaged 10½ hr., a total of 42 hr. for the four men being required.

Material used per underframe for welding averaged approximately 1,780 cu. ft. of oxygen, 1,780 cu. ft. of acetylene and 90 lb. of vanadium steel welding rod. In addition, an average of approximately 100 lb. of charcoal was required per underframe for heating the two No. 3 section while welding at the two No. 4 points, and 200 lb. of charcoal for heating up all welds to a cherry red on the following day, to relieve and equalize strains. Firebrick and sheet asbestos were employed as required.

Assuming average unit costs, the following table gives an estimate of the total oxyacetylene welding cost per tender underframe.

Labor:		
42 hr. welding time @ $0.80 per hr.		$33.60
Material:		
1,780 cu. ft. oxygen @ $1.25 per C.	$22.25	
1,780 cu. ft. acetylene @ $2.50 per C.	44.50	
90 lb. vanadium-steel rod @ $0.22 per lb.	19.80	
100 lb. charcoal (while welding) @ $0.02 per lb.	2.00	
200 lb. charcoal (heat-treating) @ $0.02 per lb.	4.00	
Firebrick, asbestos paper, etc. (estimated)	1.00	
Total material, per underframe		93.55
Total labor and material, per underframe		$127.15

Eccentric Welded Connections

By ODD ALBERT

✦ This paper is to be presented at the Annual Meeting of the American Welding Society, April, 1931, by Odd Albert, Structural Engineer, East Orange, N. J. Formerly Professor in Mathematics at West College, Sweden.

INTRODUCTION TO DESIGN METHODS OF CONNECTIONS WITHOUT MOMENT

THE design of a welded joint is rather simple as long as the line of action coincides with the center of gravity of the joint. Many tests have been made of welded joints of the types shown in Figs. 1 and 2. It has been found that the connection shown in Fig. 2 has greater strength per unit length of fillet than the connection shown in Fig. 1.

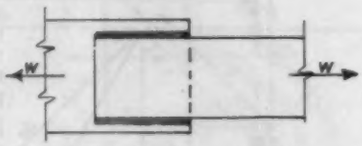


Fig. 1—Double Weld in Parallel Shear

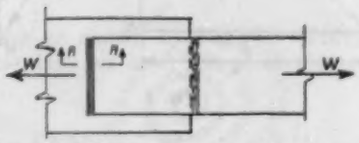


Fig. 2—Double Weld in Normal Shear

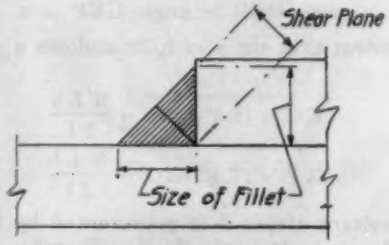


Fig. 3—Section A-A

Therefore a weld normal to the direction of the load is stronger than a weld parallel to the line of stress.

The normal line to the outline of the fillet is called throat. See Fig. 3. Being the shortest distance in the weld, the throat will determine the strength. It is easily figured that the throat t = 0.707 a, if a = the size of fillet.

A unit stress of 11300 lb. per sq. in. across the throat of a fillet has been assumed as a proper value.

For the sake of simplicity the strength of a weld is figured with a unit stress per linear inch. The strength of each linear inch may be taken as 0.707 × 11300 × the size of the fillet. The following Table 1 gives the design stresses for different sizes of fillets.

Table 1—Longitudinal Shearing Stresses (S) in Lb. per Lin. In.

Size of Fillet, in.	Stress	Size of Fillet, in.	Stress.
1/4	2000	1/2	4000
5/16	2500	9/16	4500
3/8	3000	5/8	5000
7/16	3500	3/4	6000

Thus the formula to design a centrically loaded connection will be

$$W = N \times S \qquad (1)$$

where W = the load transmitted in pounds, S = the unit shearing stress and N = the total length of the weld in inches.

Non-Symmetrical Sections

It is often necessary to use non-symmetrical sections in tension or compression. As it is of advantage to avoid secondary stresses, special joint details have been developed for non-symmetrical members, such as angles, which are frequently used in trusses. Angles would require the use of eccentric joint except for the fact that it is possible to proportion the welding used for connecting angles to other members in such a manner that the center of gravity of the member coincides with the center of the welds.

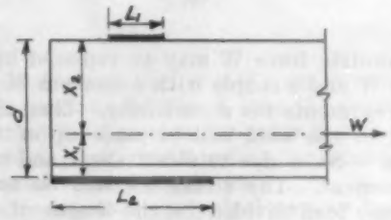


Fig. 4

Fig. 4 illustrates the design of the welds for an angle. If S is the unit stress per linear inch weld, then

$$N = \frac{W}{S} = L_1 + L_2 \qquad (2)$$

$$L_1 = \frac{L\,x_1}{d} \qquad (3)$$

$$L_2 = \frac{L\,x_2}{d} \qquad (4)$$

The Stress Distribution in Side-Welded Joints

As has already been stated the general assumption has been made that the shear is uniformly distributed along the weld. It has been proved that this is not true. An excellent paper on stresses in side welds to this effect has been published by W. H. Weiskopf and Milton Male. These authors have come to the conclusion that the shear in a weld parallel to the line of stress is a maximum at the ends of the weld. They have derived formulas and tables to find the ratio of maximum stress to average stress. This ratio becomes greater if the length of the weld increases.

It is apparent that this ratio is very near 1 for a small stress or for a high factor of safety.

Whether or not these theories are going to be used

Copyrighted by author, 1931.

in the future, the fact remains, that at the present time the standard practice is to assume the uniform distribution of the shear.

As the shear in an eccentric connection often is small in comparison to the resultant stress, the error involved, if any, becomes much smaller in an eccentric connection than in a connection without eccentricity.

THE ECCENTRIC CONNECTION

General Assumptions

Let Fig. 5 represent a welded connection with a channel fillet welded along four sides to a column. The channel supports a load W with an eccentricity of L inches

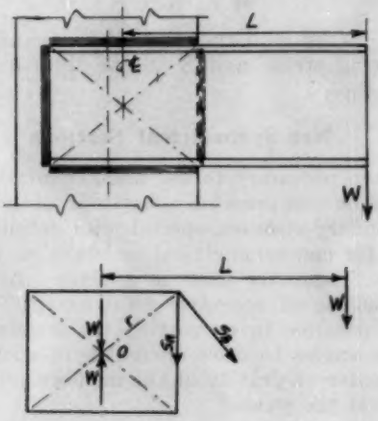


Fig. 5

The eccentric force W may be replaced by a concentric force W and a couple with a moment $M = W \times L$, where L represents the eccentricity. Then the stress in any point of the weld will be made up of two components, one — S_A — due to direct shear and one — S_B — due to moment. The stress S_A will be uniform and equal to the load divided by the length of the welded lines, while the S_B-stress will vary with the distance r of this point from the center of gravity 0 of the welded lines, and will act in directions normal to lines drawn between these points and the center 0.

If t is taken as the stress due to moment in a point at a unit distance r = l, then we get for a point with r = r, the corresponding shear to be $t \times r$, and we get the resisting moment about the center 0 to be $t \times r \times r = tr^2$, because the resisting moment equals the product of the moment shear and the lever arm.

If the distances for several points are r_1, r_2, r_3, etc., then the total resisting moment will be

$$M = r_1^2 t + r_2^2 t + r_3^2 t + \ldots.$$
$$M = t \Sigma r^2 \qquad (5)$$

The expression Σr^2 is the polar moment of inertia of the welded joint and is called I. The resisting moment M must equal the outside moment $W \times L$. Thus

$$W L = t I \qquad (6)$$

If we now consider a point at a maximum distance r from 0, we get the maximum stress S_B due to moment to be

$$S_B = t r \qquad (7)$$

or by solving for t in the equation 6 we get

$$S_B = \frac{W L r}{I} \qquad (8)$$

The expression I/r represents the section modulus of the welded section and is called P. Hence

$$S_B = \frac{W L}{P} = \frac{M}{P} \qquad (9)$$

Further the stress S_A due to vertical shear—unless otherwise noted, the load is assumed to act vertically—is uniformly distributed and is equal to the load divided by the total length of the welded lines. Hence

$$S_A = \frac{W}{N} \qquad (10)$$

where N = the total length in inches of the welded lines.

It is evident that one of the corners will receive the greatest resultant stress S. The strength of the connections will be governed by the fact that this resultant must not exceed the allowable stress.

Derivation of Formulas

Using the figure 6 we make a layout from the corner E for the forces S_A and S_B. The force S_B equaling E-F is perpendicular to the line E-O, if O represents the center of gravity of the welded lines. The force S_A equals F-H and is parallel to the direction of the load W.

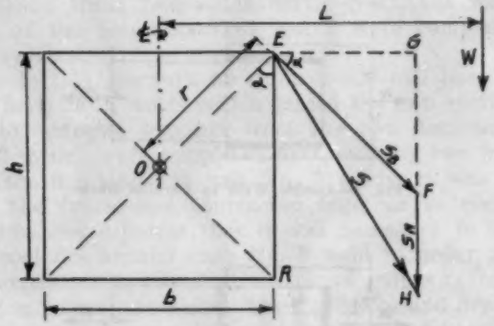


Fig. 6

It is true that the angles OEF and REG equal 90 degrees. Subtracting the angle FER from both of them we get

$$\text{angle OER} = \text{angle GEF} = \alpha$$

It is evident that $\sin \alpha = b/2r$ and $\cos \alpha = h/2r$ and therefore

$$E G = (E F) \cos \alpha = \frac{W L h}{2 I} \qquad \text{and}$$

$$G F = (E F) \sin \alpha = \frac{W L b}{2 I}$$

The resultant stress S is represented by the hypotenuse in the right triangle EGH. Therefore in accordance with the Pythagoras theorem

$$S^2 = \frac{W^2 L^2 h^2}{4 I^2} + \frac{W^2 L^2 b^2}{4 I^2} + \frac{W^2}{N^2} + \frac{W^2 L b}{I N} \quad \text{or as } h^2 + b^2 = 4r^2$$

$$S^2 = \frac{W^2 L^2 r^2}{I^2} + \frac{W^2}{N^2} + \frac{W^2 L b}{I N}$$

and by solving for S we get

$$S = \frac{W}{N} \sqrt{\frac{L^2 N^2 r^2}{I^2} + \frac{L b N}{I} + 1}$$

Thus we get the general formulas for the resultant stress

$$S = \frac{W}{N} \sqrt{A^2 B + A + 1} \qquad (11)$$

with

$$A = \frac{L\,b\,N}{I} \tag{12}$$

and

$$B = \frac{h^2 + b^2}{4b^2} = \frac{r^2}{b^2} \tag{13}$$

where W = the total eccentric load in pounds, N = the total length in inches of the welded lines, I = the polar moment of inertia of the welded lines, and r, b and h are to be found in the Fig. 6.

It will be noted that these formulas apply to any kind of a welded joint. By certain assumptions the above formulas can be very much simplified. Every value with the exception of I is very easily figured. Now those cases, that mostly occur, are going to be investigated.

Special case 1. A rectangular four-sided weld.

If a welded connection is made up of a four-sided fillet weld as shown by the Figs. 5 and 7, then the assumption may be made, that I represents the polar moment of inertia of the welded joint considered as 4

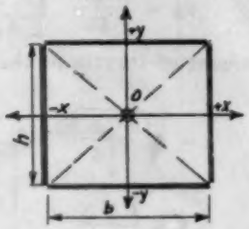


Fig. 7

straight lines as shown by Fig. 7. With reference to the principle axes we have the polar moment of inertia $I = I_x + I_y$,

where

$$I_x = 2\,b\left(\frac{h}{2}\right)^2 + 4\int_0^{\frac{h}{2}} y^2\,dy = \frac{b\,h^2}{2} + 4\left[\frac{y^3}{3}\right]_0^{\frac{h}{2}}$$

and therefore

$$I_x = \frac{3\,b\,h^2 + h^3}{6}$$

and similarly

$$I_y = \frac{3\,h\,b^2 + b^3}{6}$$

Hence

$$I = \frac{b\,(3h^2 + b^2) + h\,(h^2 + 3b^2)}{6} \tag{14}$$

Further

$$N = 2\,(b + h) \tag{15}$$

and we get thus by using above values of I and N the following value for the resultant stress

$$S = \frac{W}{2\,(h + b)}\sqrt{A^2\,B + A + 1} \tag{16}$$

with

$$A = \frac{12\,L\,b}{(b + h)^2} \tag{17}$$

and

$$B = \frac{b^2 + h^2}{4b^2} \tag{18}$$

It will be noted that the above formulas are very simple to use because complicated expressions, as for instance the polar moment of inertia, have been eliminated.

Example 1. One 10-inch channel carries a load of 20,000 pounds with an eccentricity of 20 inches. Find maximum welding stress, if a four-sided weld is used with b = 10 inches.

With L = 20 inches, b = 10 inches and h = 10 inches, we get from formula 17

$$A = \frac{12\ .\ 20\ .\ 10}{(10 + 10)^2} = 6$$

and from formula 18

$$B = \frac{10^2 + 10^2}{4 \times 10^2} = .5$$

and therefore the formula 16 becomes

$$S = \frac{20000}{2\,(10 + 10)}\sqrt{6^2 \times .5 + 6 + 1} = 2500.$$

Answer: The maximum resultant stress is 2500 pounds.

Special case 2. A horizontal two-sided weld.

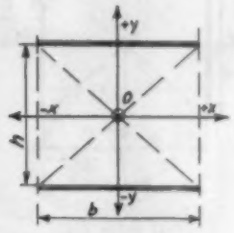


Fig. 8

If a welded connection is made up of two horizontal fillet welds as shown by Fig. 8, then the assumption may be made, that I represents the polar moment of inertia of the welded joint considered as two straight horizontal lines as shown by the figure.

With reference to the principal axes we have the polar moment of inertia $I = I_x + I_y$,

Where

$$I_x = 2\,b\left(\frac{h}{2}\right)^2 = \frac{b\,h^2}{2}$$

and

$$I_y = 4\int_0^{\frac{b}{2}} x^2\,dx = 4\left[\frac{x^3}{3}\right]_0^{\frac{b}{2}} = \frac{b^3}{6}$$

and therefore

$$I = \frac{b\,(3\,h^2 + b^2)}{6} \tag{19}$$

Further

$$N = 2\,b \tag{20}$$

and we get thus by using the above values of I and N the following value for the resultant stress

$$S = \frac{W}{2\,b}\sqrt{A^2\,B + A + 1} \tag{21}$$

with

$$A = \frac{12\,L\,b}{3\,h^2 + b^2} \tag{22}$$

and

$$B = \frac{h^2 + b^2}{4\,b^2} \tag{23}$$

Example 2. A 12-inch channel connected to a column with a horizontal two-sided weld, carries an eccentric load of 18,000 pounds. If the eccentricity is 12

inches and the value of b is 10 inches, find the maximum stress in the weld.

With L = 12 inches, b = 10 inches and h = 12 inches we get by using formula 22

$$A = \frac{12 \times 12 \times 10}{3 \times 12^2 + 10^2} = 2.71$$

and from formula 23

$$B = \frac{12^2 + 10^2}{4 \times 10^2} = .61$$

and therefore the formula 21 becomes

$$S = \frac{18000}{2 \times 10}\sqrt{2.71^2 \times .61 + 2.71 + 1} = 2560.$$

Answer: The maximum resultant stress is 2560 pounds per inch.

Special case 3. A vertical two-sided weld.

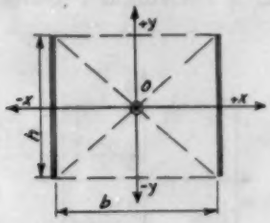


Fig. 9

If a welded connection is made up of two vertical fillet welds as shown by figure 9, then the assumption may be made, that I represents the polar moment of inertia of the welded joint considered as two straight vertical lines as shown by the figure.

With reference to the principal axes we have the polar moment of inertia $I = I_x + I_y$,

Where

$$I_x = 4\int_0^{\frac{h}{2}} y^2\,dy = 4\left[\frac{y^3}{3}\right]_0^{\frac{h}{2}} = \frac{h^3}{6}$$

and

$$I_y = 2h\left(\frac{b}{2}\right)^2 = \frac{h\,b^2}{2}$$

and therefore

$$I = \frac{h\,(h^2 + 3b^2)}{6} \qquad (24)$$

Further

$$N = 2h \qquad (25)$$

and we get thus by using the above values of I and N the following expression for the resultant stress

$$S = \frac{W}{2h}\sqrt{A^2 B + A + 1} \qquad (26)$$

with

$$A = \frac{12\,L\,b}{h^2 + 3\,b^2} \qquad (27)$$

and

$$B = \frac{h^2 + b^2}{4\,b^2} \qquad (28)$$

Example 3. A 12-inch channel connected to a column with a vertical double weld carries an eccentric load of 18,000 pounds. If the eccentricity is 12 inches and the value of b is 6 inches, find the maximum stress in the weld.

With L = 12, b = 6 and h = 12, we get by using formula 27

$$A = \frac{12 \times 12 \times 6}{12^2 + 3 \times 6^2} = \frac{24}{7} = 3.43$$

and from formula 28

$$B = \frac{12^2 + 6^2}{4 \times 6^2} = \frac{5}{4} = 1.25.$$

and therefore the formula 26 becomes

$$S = \frac{18000}{2 \times 12}\sqrt{3.43^2 \times 1.25 + 3.43 + 1} = 3280.$$

By using chart 1c, enter for L/b = 12/6 = 2, turn down for h/b = 12/6 = 2 and read E = 4.37.

Hence

$$S = \frac{18000}{2 \times 12} \times 4.37 = 3280 \text{ pounds.}$$

Bending Only Considered

It has previously been proven—formula (8)—that the stress due to the bending was

$$S_B = \frac{W\,L\,r}{I}$$

where I = the moment of inertia of the weld lines
We have

$$r = \sqrt{\frac{h^2 + b^2}{4}}$$

and

$$A = \frac{L\,b\,N}{I}$$

and therefore

$$S_B = \frac{W\,A}{b\,N}\sqrt{\frac{h^2 + b^2}{4}}$$

Further

$$B = \frac{h^2 + b^2}{4\,b^2}$$

and therefore

$$S_B = \frac{W}{N}A\sqrt{B} \qquad (29)$$

where the values of A and B have previously been derived, and may be obtained from Table 2 for some commonly used cases.

General Design Formulae

The following table is a summary of the foregoing and may be useful in the design of the maximum stresses for different conditions.

Thus we have for shear and bending the maximum fiber stress

$$S = \frac{W}{N}\sqrt{A^2 B + A + 1}$$

and for bending alone the maximum fiber stress

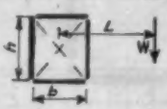
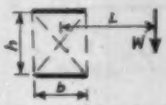
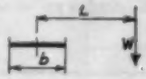
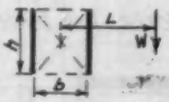
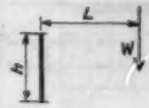
$$S_B = \frac{W}{N}A\sqrt{B}$$

It will be noted that these expressions do not contain any complex quantities but only values that can be taken direct from the figures.

Comparison Between Rivet and Weld Formulae

A vertical double weld may be compared with a group of rivets in two vertical rows with an infinite

TABLE 2—VALUES OF A, B AND N FOR DIFFERENT CONDITIONS

Case		N	A	B
A. 	Foursided Weld	$2b + 2h$	$\frac{12\ L\ b}{(b + h)^3}$	$\frac{b^2 + h^2}{4\ b^2}$
B. 	Horizontal Double Weld	$2\ b$	$\frac{12\ L\ b}{3\ h^2 + b^2}$	$\frac{b^2 + h^2}{4\ b^2}$
C. 	Horizontal Single Weld	b	$S = \frac{W}{N}\left(\frac{6\ L}{b} + 1\right)$ $S_B = \frac{W}{N} \times \frac{6\ L}{b}$	
D. 	Vertical Double Weld	$2h$	$\frac{12\ L\ b}{h^2 + 3b^2}$	$\frac{b^2 + h^2}{4\ b^2}$
E. 	Vertical Single Weld	h	$S = \frac{W}{N}\sqrt{\frac{36\ L^2}{h^2} + 1}$ $S_B = \frac{W}{N} \times \frac{6\ L}{h}$	

number of rivets in each row as has been shown in Fig. 10.

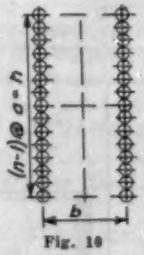


Fig. 10

From an article by the author in *Civil Engineering* for February, 1931—Designing Riveted Connections with Charts and Tables:—a general rivet formula is given as

$$S = \frac{W}{N}\sqrt{A^2\ B + A + 1} \qquad (a)$$

where S = the maximum resultant stress on an extreme rivet, W = the load and N = the number of rivets. For two vertical rows the following values of A and B are given, where a = the vertical and b = the horizontal spacing, and n = number of rivets in each row.

$$A = \frac{12\ L\ b}{a^2\ (n^2 - 1) + 3b^2} \qquad (b)$$

$$B = \frac{a^2\ (n - 1)^2 + b^2}{4b^2} \qquad (c)$$

It will be found that this formula—a—has exactly the same appearance as formula (11). In the weld-formula N = the total length of welds.

The denomiator of (b) may be written

$$= a\ (n - 1)\ [a(n - 1) + 2a] + 3b^2$$

The term $a(n - 1) = 2$. The vertical spacing a is very small for an infinite number of rivets, and therefore $2a = 0$. Hence the whole expression becomes $h^2 + 3b^2$ and

$$A = \frac{12\ L\ b}{h^2 + 3b^2}$$

The numerator in the expression for (c) may be written $a(n - 1)\ a(n - 1) + b^2$, or with $a(n - 1) = h$ the value of B will be

$$B = \frac{h^2 + b^2}{4\ b^2}$$

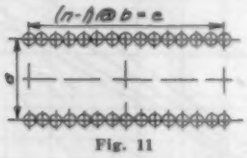


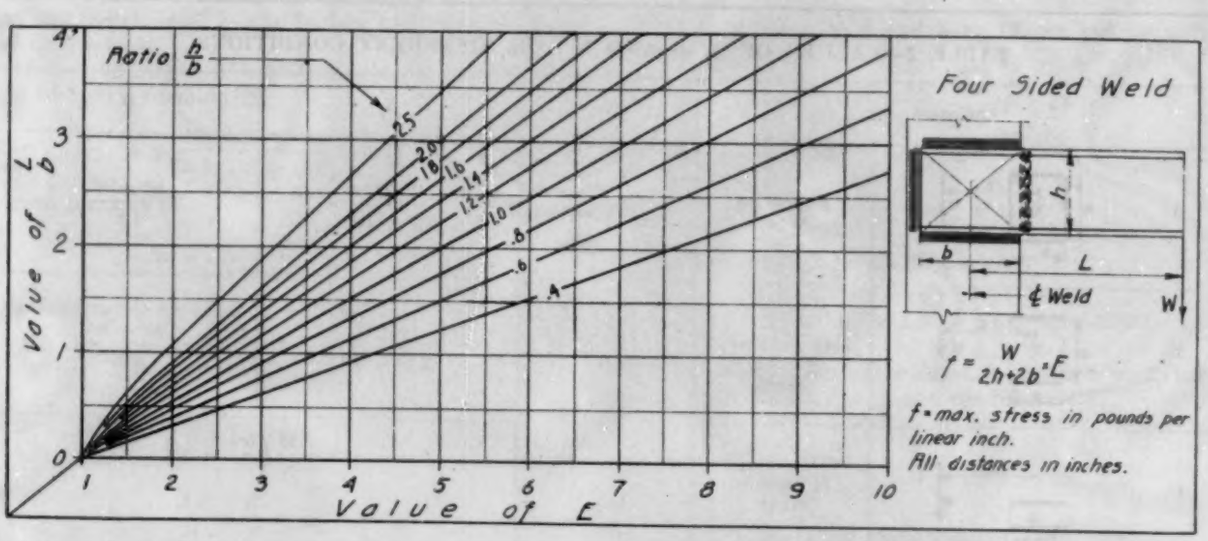
Fig. 11

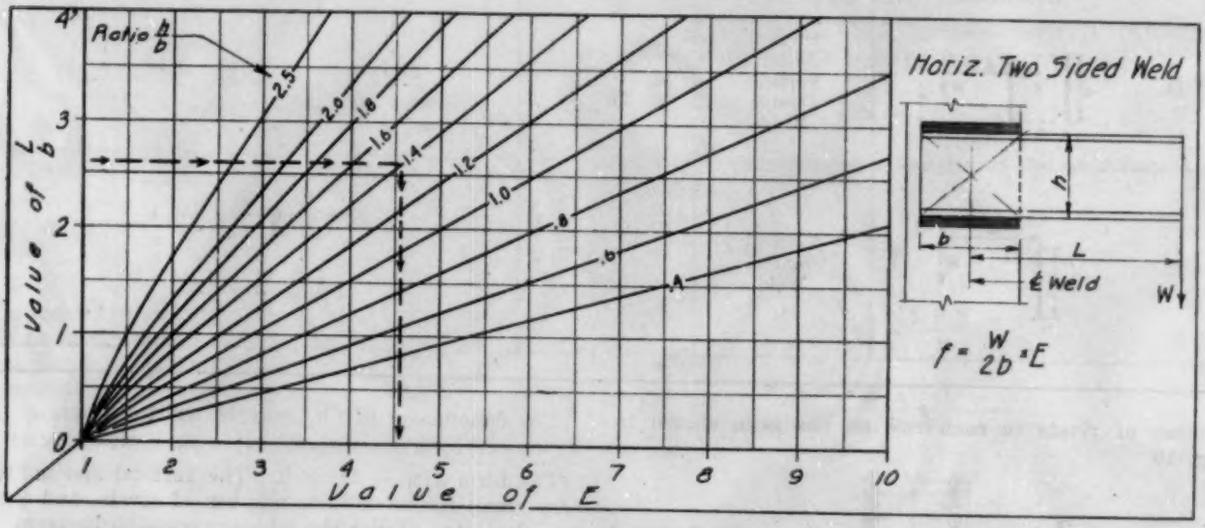
These expressions agree exactly with the corresponding values for the welded connections if h represents the length of the welds and b is the distance between them.

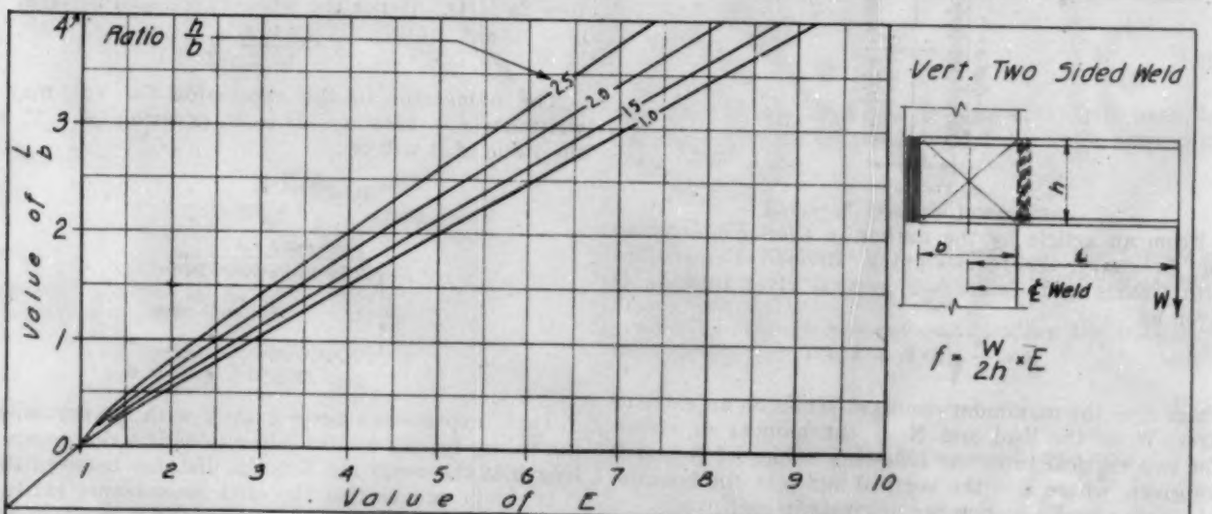
It can be proven that the same resemblance exists between the horizontal double weld and a rivet group—see Fig. 11—with an infinite number of vertical rows with two rivets in each row.

The Direction of the Eccentric Load Is Not Vertical

In the previous discussions and derivations one of the assumptions has been that the resultant load has been acting vertically. Should this not be the case as is







Example. An excentric weld connection carries 15000 pounds. If the eccentricity L=26", h=14" and b=10", find the max. stress due shear and bending. Use horizontal two sided weld. Follow dotted lines. Enter chart at left for L/b = 26/10 = 2.6; turn down for h/b = 14/10 = 1.4 and read E = 4.55. Total length of welds N = 16+10 = 26. Hence $f = \frac{15000}{26} \times 4.55 = 2620$ #/"

Welded Connections
Max. Stress for Excentric Load

Copyright, 1931 by Odd Nlbert Plate SW1

Chart No. 1

shown by Fig. 12, then the following assumptions may be made.

Add at the center of gravity O of the weld lines two opposed forces parallel to the direction of the eccentric load, each equal to W. No change in deformation results from this arrangement.

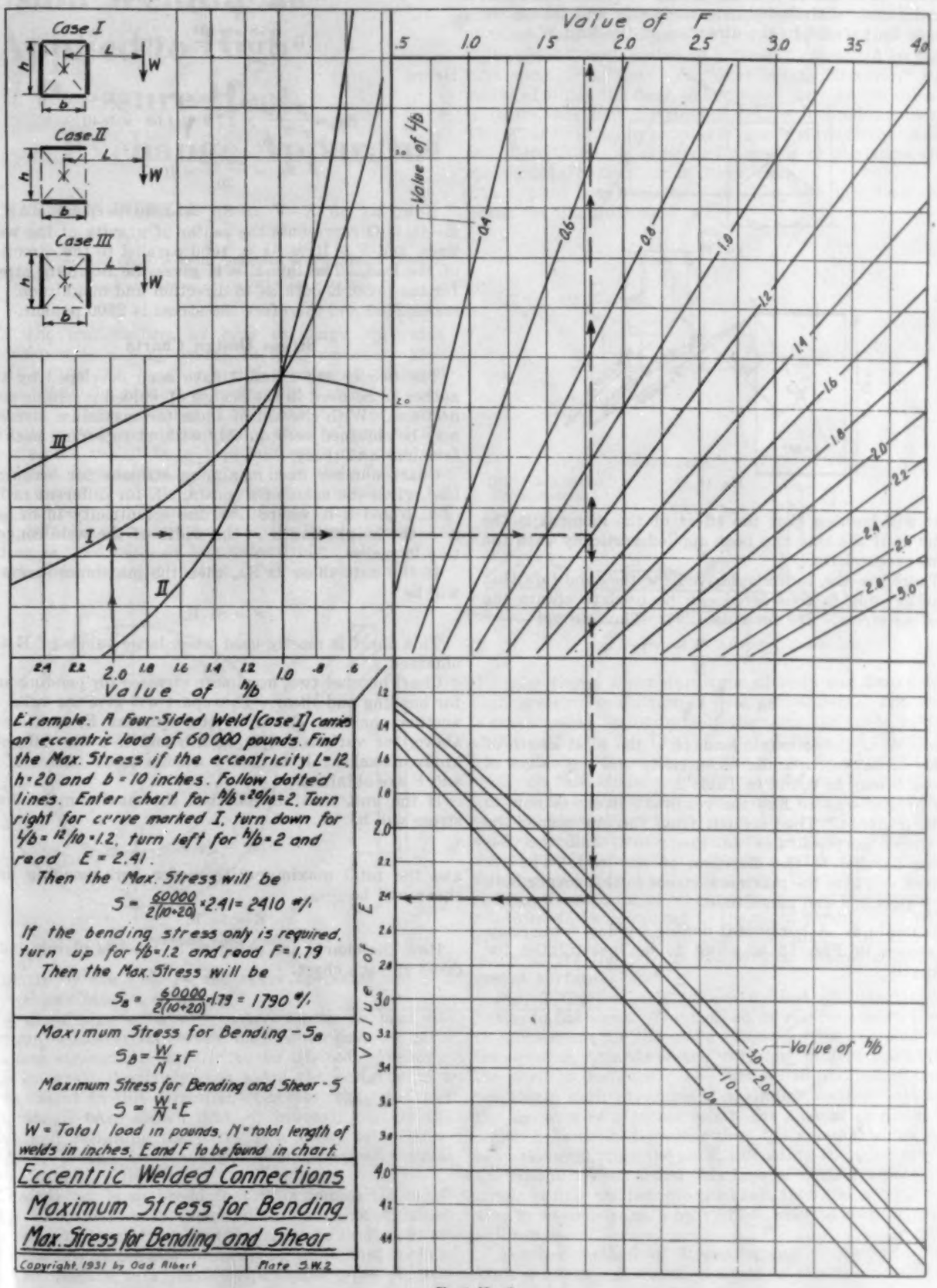

Case I
Case II
Case III
h
b
L
W
Value of F
Value of h/b
Value of E
Value of h/b
Example. A four-Sided Weld [Case I] carries an eccentric load of 60000 pounds. Find the Max. Stress if the eccentricity L=12, h=20 and b=10 inches. Follow dotted lines. Enter chart for h/b=20/10=2. Turn right for curve marked I, turn down for L/b=12/10=1.2, turn left for h/b=2 and read E=2.41.
Then the Max. Stress will be
S = 60000/2(10+20) ×2.41 = 2410 #/
If the bending stress only is required, turn up for L/b=1.2 and read F=1.79
Then the Max. Stress will be
S_B = 60000/2(10+20) ×1.79 = 1790 #/
Maximum Stress for Bending = S_B
S_B = W/N × F
Maximum Stress for Bending and Shear = S
S = W/N × E
W = Total load in pounds, N = total length of welds in inches, E and F to be found in chart.
Eccentric Welded Connections
Maximum Stress for Bending
Max. Stress for Bending and Shear
Copyright 1931 by Oda Albert
Plate 5.W.2

Chart No. 2

The effect of the original loading then may be considered as equal to a center load W and a moment of WL, if L represents the perpendicular distance from the line of action of W to the center O. This center load is uniformly distributed over the welds and causes the stress S_A parallel to the direction of the load W.

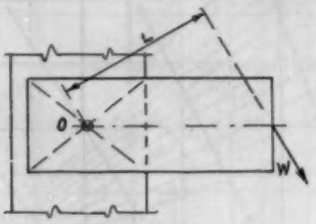


Fig. 12

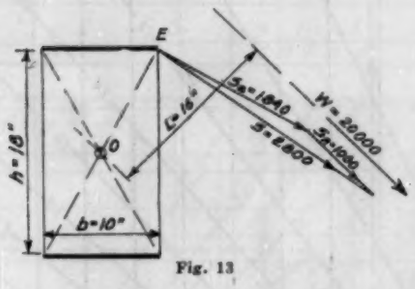


Fig. 13

It will be seen that the effect of the moment is the same as if the load had been applied vertically with the same eccentricity.

Therefore the formula derived for the condition that bending only is considered can be used to obtain the bending stress. See formula (29). Thus we get

$$S_A = \frac{W}{N}$$

$$S_B = \frac{W}{N} A \sqrt{B}$$

where W = the eccentric load, N = the total length of welds in inches, L = the eccentricity and the values of A and B may be found in Table 2.

The best way to find the resultant stress is now to make a layout. Thus lay out from the one corner the S_B-stress perpendicular to the r-line, and the S_A-stress parallel to the direction of the load. The resultant will give the maximum stress in this corner both as to direction and magnitude.

Example 4. A horizontal double welded connection as shown in Fig. 13 is going to be investigated for strength.

With L = 16 inches, h = 18 and b = 10 inches we get from Table 2

$$A = \frac{12 \times 16 \times 10}{3 \times 18^2 + 10^2} = 1.79$$

$$B = \frac{18^2 + 10^2}{4} = 1.06$$

Hence

$$S_B = \frac{20000}{20} \times 1.79 \sqrt{1.06} = 1840$$

$$S_A = \frac{20000}{20} = 1000$$

Now, lay off E—F = S_B = 1840 perpendicular to E—O, if O represents the center of gravity of the weld lines, and F — H = S_A = 1000 parallel to the direction of the load. The line E — H gives the resultant stress for the point E both as to direction and magnitude. It scales 2800 and therefore the stress is 2800 pounds.

Stress Design Charts

The two charts 1 and 2 have been developed by the author to be used in the design of welded eccentric connections. With the aid of them the maximum stresses may be obtained very quickly without referring back to formulas and theory.

Chart number one, maximum stresses for eccentric load, gives the value of a constant E for different ratios of L/b and h/b, where L = the eccentricity in inches, h = the height and b = the width of the weld connection in inches.

If the unit shear is S_A, then the maximum stress S will be

$$S = S_A E.$$

This chart is mostly used when large values of E are obtained.

Chart number two, maximum stresses for bending and for bending and shear. This chart will give the value of another constant F and of the constant E, mentioned above, for various ratios of h/b and L/b for different kinds of welds. It is useful when smaller values of E and F are obtained.

If the unit shear is S_A, then the maximum bending stress will be

$$S_B = S_A F$$

and the total maximum stress for both bending and shear will be

$$S = S_A E.$$

How the charts are going to be used is plainly indicated on each chart.

Fusion Welding as Applied to High Pressure Heat Exchange Apparatus

By MARSELIS POWELL

✦ This paper is to be presented at the Annual Meeting, A. M. S., April, 1931, by Marselis Powell, General Foreman in charge of Welding of The Whitlock Coil Pipe Co.

IN the manufacture of heat exchange apparatus welding is a very useful, in fact, necessary tool. It assists the designer and fabricator in no small degree. And the product is materially better. In fact, whenever a vessel is designed, whether it be for a new or an old service, whether it be of steel or some of the newer alloys, can it be welded is always the question and almost invariably the answer is in the affirmative.

The company which I represent manufactures a great number of different types of heat exchangers, for many different classes of service. On nearly every one welding is used more or less extensively. All welding is done under constant control. Test samples are made

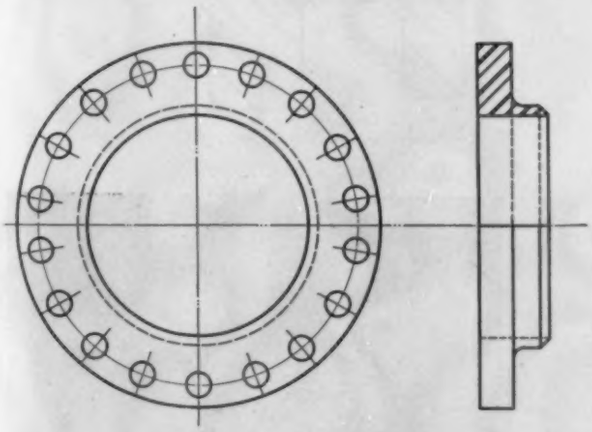


Fig. 1—Standard Shell End Flange

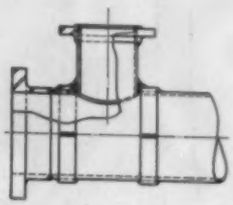
regularly by the welders and these are examined and the welders rated accordingly.

In the design of any pressure vessel, or heat exchanger, whatever its service may be, to have all parts of equal strength is greatly to be desired. Welding, with its great flexibility, has aided the designer to a great extent in this direction. Careful study and test applications have shown that, by properly placing the welds and designing the parts of a vessel or heat exchanger, it can be made to have practically equal strength in all places.

The subject is so broad that it is impossible to attempt to cover it with even approximate thoroughness. The scope of this article will therefore be limited to selecting a few of the more interesting individual applications of welding to a very few principal types of pressure vessels and heat exchangers.

The general class of multitubular heat exchanger includes many different designs, each particular design, being particularly well adapted to a particular class, or a range of classes, of specific service. Essentially, however, all units in this general class consist of a number of tubes, mounted in parallel secured at both ends in a "tube sheet," and encased in a "shell." Mounted on the tube sheet is a "head" or "distributing chamber," by means of which the fluid, to be passed through the tubes, is introduced and distributed in the desired manner. The other fluid being handled is passed through the shell, and distributed, as desired, by means of the tube arrangement, "baffles," or in other ways.

A typical heat exchanger of this class has been selected for illustration.



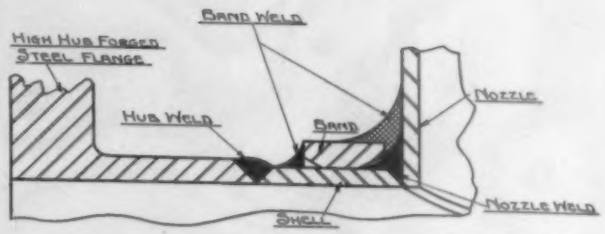


Fig. 2—Method of Attaching Nozzle

Fig. 1 shows a standard type of shell end flange for high pressure multitubular heat exchangers. The hub is machined to approximately the same thickness as the shell and butt welded to it. A shell flange of this type has distinct advantages over the plain welded ring construction in that the weld is removed from the point of greatest stress and also it is a butt weld between two parts of approximately the same thickness, rather than a fillet weld between a comparatively thin shell and a heavy ring, which facilitates to a marked degree, the welding operation itself. Moreover this type of flange reduces the amount of warp in the face of the flange to a minimum, as compared to the plain welded ring with fillet weld. After welding a light finish cut may be taken across the face of the ring to insure a perfect gasket surface.

Fig. 2 illustrates a typical method of attaching a nozzle to the shell. The method of reinforcement used, to compensate for the metal removed from the shell by the opening, depends on the working pressure for which the shell is designed. The method illustrated is used for fairly high pressures. A similar method involves the use of a reinforcing collar, the amount of metal in which is somewhat greater than the amount which has been removed from the shell, in cutting the opening for the nozzle. When using this type of reinforcement the nozzle is first welded into the shell, then the reinforcing ring is welded, using a heavy fillet weld, to both the shell and nozzle.

Another method of strengthening nozzle welds for high working pressures, consists in "flaring" or "belling" either the end of the nozzle or the edges of the

opening in the shell. This somewhat reinforces the opening and, at the same time, removes the weld from the point of greatest stress.

It may be interesting, at this point, to briefly describe and illustrate some of the results obtained from a Photo-Elastic investigation involving the theory of this latter method of securing a nozzle to a shell, or attaching any member, such as an expansion joint, to a shell. This investigation was undertaken with a view to studying the magnitude and distribution of internal stresses, through a connection of this type, when subjected to the bending stresses imposed by the operation of an expansion joint.

A thorough description of the experimental methods

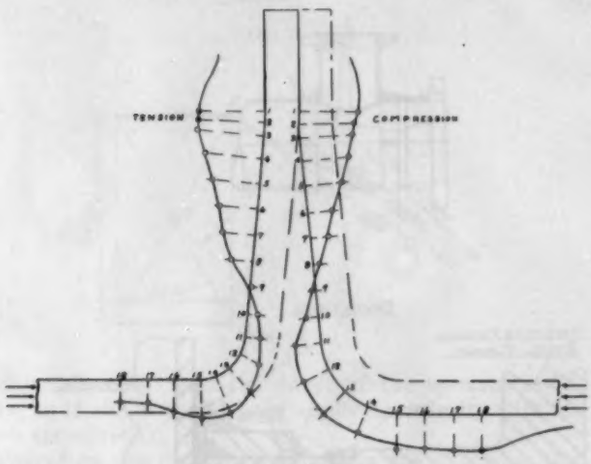


Fig. 3

and results, though extremely interesting, would be out of place here. It is possible therefore only to illustrate the principal results obtained. Fig. 3 is a plot of the magnitudes of the stresses on the inner and outer faces of the metal. The lengths of the dotted lines indicate the magnitudes of the stresses, tensile stresses being plotted outwardly and compressive stresses inwardly (that is inwardly and outwardly with regard to the body of the metal) from the face concerned. Note the inflection points in each face of the diaphragms of the expansion joints, where the stresses become zero. Note also the stresses around the radii, where the hubs of the expansion joint join the shell. A number of similar Photo-Elastic investigations, covering various typical structures, used in the building of heat exchange apparatus and subjected to bending and other complicated stresses in the normal operation of the heat exchangers, have shown similar results.

The use of welding in connection with the manufacture of heads for high pressure heat exchangers is illustrated in Fig. 4. This head is made of a single steel forging with the dividing rib welded in as shown.

The welding on of heads to the closed ends of heat exchanger shells is, of course, a familiar application. At such points the weld is usually of the plain butt type, and generally of the single V design. The design of the head is important in order to insure equal strength at all points, as already referred to. Recent investigations having demonstrated the fact that heads having a semi-ellipsoidal contour develop uniform stresses throughout, and hence have no tendency to deform, under internal pressure, head designs aproximating such a contour are desirable. By the proper selection of the radius of curvature of the bumped portion of the head, and of the knuckle radii, bumped heads having shapes acceptably close to this standard, can be secured.

An interesting application of welding in connection with a special type of head, is seen in the most highly developed design of ammonia receiver. In this case the bumped head is not welded, by means of a butt joint, to the end of the shell, but is slipped inside the shell, with

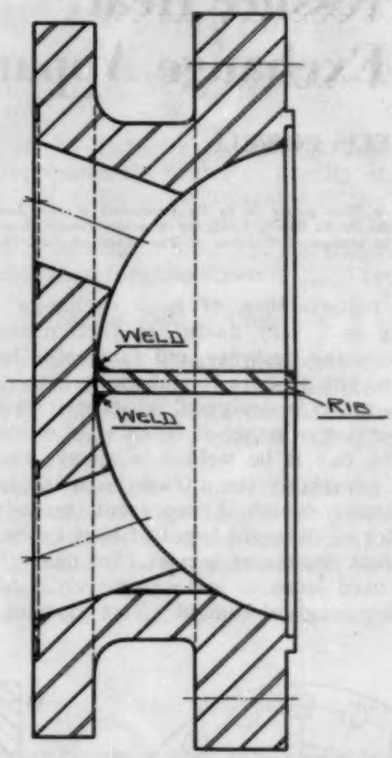


Fig. 4—Fabrication of Heads for Heat Exchangers

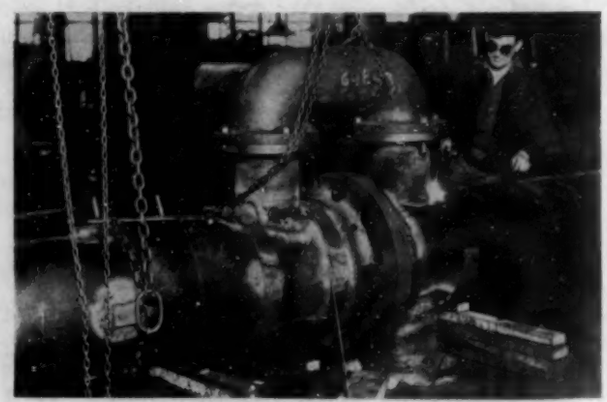


Fig. 5—Joining Nozzle to Shell

the bump turned in, or in other words, it is a concave or "minus" head. Then a fillet weld is used to secure the head to the shell. The reason for placing the head with the bump inward is to provide for the possibility of the receiver being closed off tight when full, or practically full, of liquid. In such a case, if an increase in temperature occurs, the pressure in the receiver could of course increase to a practically unlimited amount. With the design described however, this would simply result in the reversing of the bumped heads, the resul-

tant increase in the volume of the receiver being ample to compensate for any conceivable increase in the temperature and volume of the liquid. Actual tests to destruction on receivers of this design, have resulted in completely reversing the bumped head curvatures, without disturbing the welds. Such receivers are normally tested to 300 lb. pressure, for maximum safe working

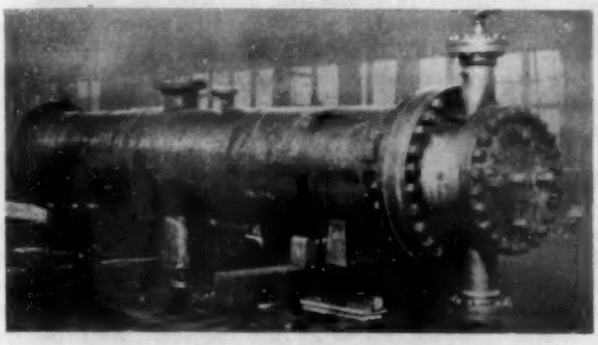


Fig. 6—An Extraction Feed Water Heater

pressures of about 180 lb., and internal pressures of about 1000 lb. are required to reverse the heads.

Fig. 5 shows a method by which a nozzle is joined to a shell where absolute alignment is necessary. In this particular case the two tube sheets were bolted together and the cross-over bolted to one nozzle which had already been welded into the shell, the other nozzle was bolted to the cross-over and welded while still held in place by the bolts. After welding both nozzles were relief annealed and a perfect gasket surface alignment was obtained. This picture also shows a method already described of nozzle reinforcement.

Fig. 6 shows an extraction feed water heater which was designed around the use of welded forged steel as a substitute for steel castings. The unit consists of a shell and tube bundle. Straight tubes are used, expanded into a fixed tube sheet at one end and into a floating tube sheet at the other. This floating tube

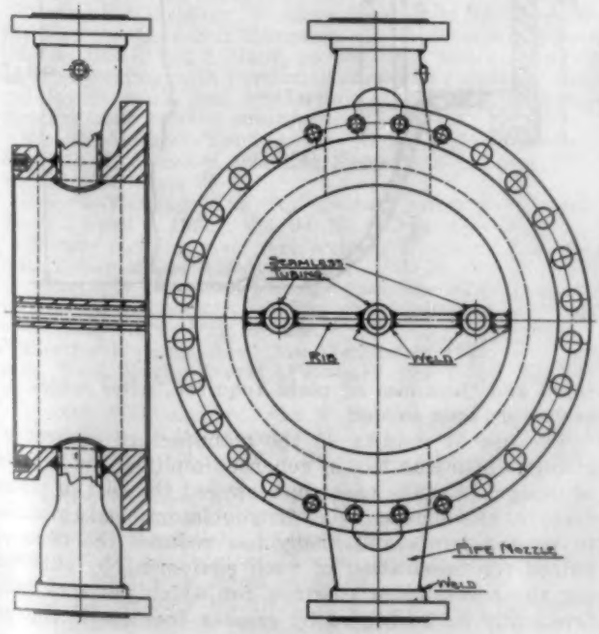


Fig. 7—Distributing Chamber

sheet is free to move, which allows for differential expansion between the tube bundle and shell. This particular unit is a two pass unit.

The distributing chamber shown in Fig. 7 is a round forging into which two nozzles were welded for inlet and outlet connections. These nozzles are eight inch extra heavy pipe flattened at one end. The flattened ends of these pipes were welded into the main body of the water chamber forging directly opposite each other. On the outer ends of these pipes extra heavy forged steel flanges were welded which gave a very satisfactory nozzle construction. At 90° to the center line of these nozzles dividing the internal portion of the water chamber into two equal parts, a rib was welded. This rib consisted of three pieces of heavy wall steel tubing and four pieces of rolled steel plate welded together to form a baffle straight across the water chamber. The three pieces of steel tube formed the holes for the tie studs between the outer head and tube sheet.

The floating head, Fig. 8, that is the rear head, which

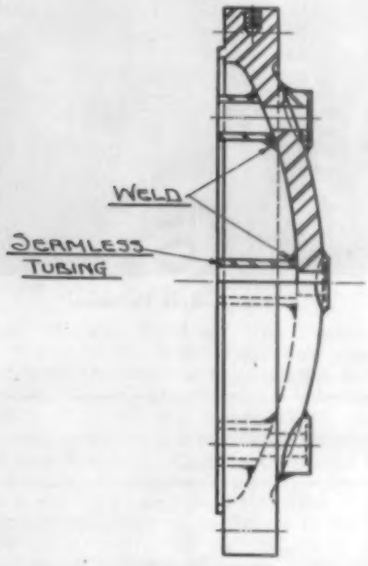


Fig. 8—Floating Head

bolts to the floating tube sheet was also a forging somewhat in the shape of a dished head. Bosses were welded on the outside of this head and directly opposite these bosses on the inside heavy wall, tubes were welded. Holes were drilled through the bosses for tie studs.

On the shell and rear head the hub type ring was used to a great advantage. A ring was welded to each end of the shell and to a large knuckle radius bumped head to form the rear head. The rear head fabricated in this manner has distinct advantages, it is lighter than a casting would be for the same strength and free from any porous condition so often found in castings of this nature. The hub of the ring and the flange of the dished head give considerable length in the head, which is the same diameter as the shell, so that the floating head and tube sheet of the unit are very accessible when the rear head is removed.

Fig. 9 shows a heat exchanger of somewhat different design which has a different method of compensating for differential expansion between the tubes and shell. In this type, the shell and tube sheets are welded together. A flange is turned up on each end of the shell and a tube sheet welded to it with an edge weld. This flange at the end of the shell forms the expansion joint

to take care of any differential expansion in the heat exchanger. The distributing head is held against the tube sheet by means of backing rings which are bolted together. These bolted backing rings also tend to reinforce the edge weld. This construction is such that the stresses due either to expansion or contraction caused by temperature changes, or to high operating pressures in the shell, are uniformly distributed.

In certain cases where high temperature changes take place under rather high pressures, a permanently tight joint between tube and tube sheet is required. Here again welded construction plays an important part. For instance, ¾-in. dia. 16-gage steel tubes are welded into steel tube sheets two or three inches thick. This gives a very satisfactory joint which remains tight after numerous temperature changes of 500° and under 2000 lb. pressure.

Fig. 10 shows the assembly of a welded autoclave which is a special type of pressure vessel. This unit

Fig. 9—Heat Exchanger

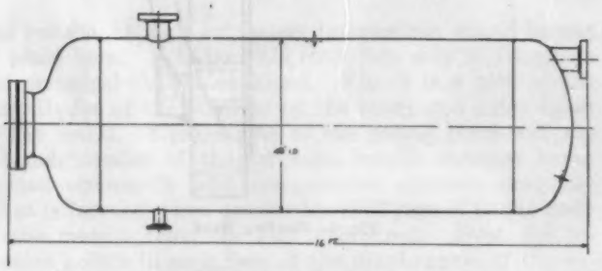


Fig. 10—Welded Autoclave

is approximately 4 ft. in dia. by 16 ft. long built for a normal working pressure of 200 lb. per sq. in.

The shell plate which is ⅝ in. thick was first cut to size and the edges scarfed 45° for double V welding. Plate was then rolled, the longitudinal seam welded and the bumped heads similarly scarfed and welded to the shell.

Shell nozzles consist of short pieces of extra heavy steel pipe, one end of which was welded to the shell, the other end welded into a forged steel flange.

The 16 in. dia. manhole is of special interest. The pressures under which the autoclave were to be subjected and the fact that all joints must be made absolutely and permanently tight against gas leakage made it advisable to adopt a more rigid construction than that provided by the standard type of flanged-in manhole with pressed steel cover. In order not to weaken the bumped head and also in order to provide a weld in direct tension the head was flanged outward as shown in Fig. 11 and a forged high hub flange was double V welded as shown. The bumped steel head was then reinforced to compensate for the metal removed by welding a steel band around the manhole opening on the inside of the autoclave.

Welding plays a very important part in the manufacture of steel coils which are used extensively as heat exchangers. In some of these coils the pipe is welded into one long piece and the coil bent from this piece. These coils are bent either hot or cold depending upon the size of the pipe and the diameter of the coil. In both cases the welds in the long length have to go through the bending rolls the same as the pipe itself.

In some of these coils, particularly oblong coils or square corner coils, the pipes are bent first and welded afterward into the complete coil.

In general the use of welding in the fabrication of heat exchange equipment has been continually increasing. Expensive castings of iron and steel have been substituted by built up shapes of steel made possible by welding. Cast iron and cast steel saddle parts riveted to the shell to which piping connections were made have given way to lap welded steel pipe nozzles, one end of which is welded into the shell, the other end welded into a forged steel flange to which the piping connections may be attached by means of through bolts. Shell rings previously built of cast iron or cast steel and riveted to the shell to act as bolting rings have been substituted by various types of forged steel rings welded to the shell as previously mentioned. In the larger size shells frequently built of lap welded or hammer welded steel pipe have been superseded by shells rolled from steel plate in accordance with the desired steel specifica-

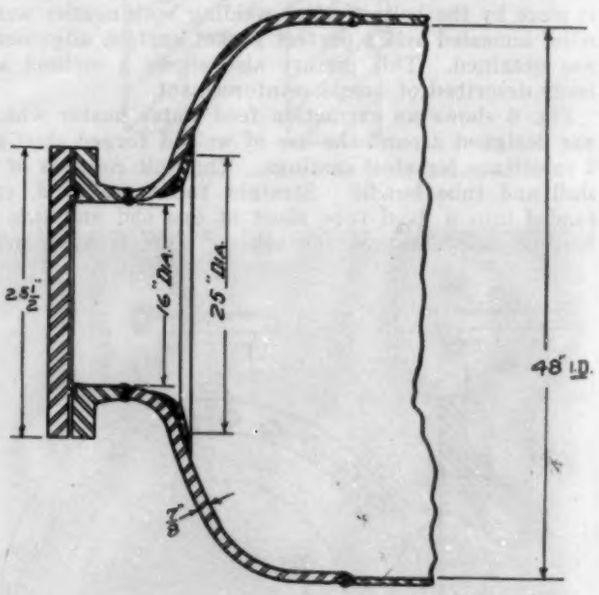


Fig. 11—Flanged Head

tions and thickness of plate required, after which the seams are butt welded.

The use of welding in the manufacture of heat exchange apparatus has in general simplified the problem of design, in many cases has lowered the cost of manufacture, has done away with troublesome leaks peculiar to riveted joints and finally has reduced the time required for fabrication of such equipment by eliminating the necessity of castings for which patterns must frequently be made and by greater freedom in the use of stock parts.

Current Welding Literature

Airplane Manufacture—Oxy-Acetylene Welding. Production of Aircraft Specialties. Oxy-Acetylene Tips (March, 1931), Vol. 10, No. 3, pp. 57-59. Use of oxy-acetylene welding of chrome-nickel-steel, aluminum and duralumin parts of airplane.

Aluminum—Electric Welding. Arc Welding Aluminum. G. T. Kerr. West. Machy. World (February, 1931), Vol. 2, No. 2, p. 70.

Arc Welding Broken Crankshafts. The Welding Engineer (March, 1931), Vol. 16, No. 3, pp. 36-38. Confronted with a complicated problem and unable to "Talk it over," the welder evolves a procedure from his experience.

Autogenous Welding—Electric. Railway Journal (March, 1931), Vol. 37, No. 3, pp. 32-33.

Boiler Codes—A.S.M.E. Welded Power Boilers Covered by New Code Proposal. Power (March 17, 1931), Vol. 73, No. 11, p. 445. Establishes three classes of pressure vessels and four grades of welding; boiler drums, included in class 1, require grade A welding.

Brazing. Multiple-Joint Brazing in Hydrogen Atmosphere. H. M. Webber. Am. Mach. (Oct. 30, 1930), Vol. 73, No. 18, pp. 697-698.

Bridge Construction—Welding. Reconditioning Short-Span Steel Bridges by Welding. C. B. Dannenberg. Roads and Streets (March, 1931), Vol. 71, No. 3, pp. 97-99. Report for County Highway Officials' division of American Road Builders' Association; excessive deformation of chord angles checked by welding; continuity of stringers effected by welding; fillet welds supplemented by rivet welds; web-to-chord connection of small truss strengthened by welding; reinforcing low truss spans; increasing resistance of stringers; welding top-chord knee-brace; strengthening floor-beams; restoring efficiency of rusted members; welding applied to floor system.

Bronze Welding Process. De W. Endicott. Can. Machy. (March 5, 1931), Vol. 43, No. 5, pp. 46, 48, 50 and 52.

Buildings, Steel—Electric Welding. Arc Welding Economies. F. P. McKibben. Civil Eng. (N. Y.), Vol. 1, No. 6 (March, 1931), p. 550.

Cast Iron—Electric Welding. The Use of Pure Iron Electrodes for Welding Cast Iron. H. D. Lloyd and J. S. G. Primrose. Iron and Steel Industry (February, 1931), Vol. 4, No. 5, pp. 175-176. Also in Mech. World (March 6, 1931), Vol. 89, No. 2305, pp. 215-217.

Columns, Steel Welded. Compressive Tests of Jointed H-Section Steel Columns. J. H. Edwards, H. L. Whittemore and A. H. Stang. U. S. Bur. Standards—Jl. Research, Vol. 6, No. 2 (February, 1931), pp. 305-337.

Conveyors—Welding. Welding Practice at San Francisco Plant of the Link-Belt Company. G. P. Newton. Welding (March, 1931), Vol. 2, No. 3, pp. 188-190. Survey of advantages of welding with particular regard to simplified design and layout work, and production of conveyor equipment stronger than riveted construction.

Electric Motors—Welding. Resistance Welding of Motor Frames. M. Thomson. Welding Engineer (February, 1931), Vol. 16, No. 2, pp. 36-38.

Electric Welding—The New Tool of Industry. Electrical World (April 4, 1931), Vol. 94, No. 14, pp. 636-638.

Electric Welding, Arc. Arc Welding Everdur. T. E. Jerabek. Boiler Maker (March, 1931), Vol. 31, No. 3, pp. 68-69. Property of copper-silicon-manganese alloy, known as everdur; advantageous welding characteristics; procedure of metallic arc welding process.

Electric Welding, Arc. Arc Welding in 1931. J. F. Lincoln. West. Machy. World (February, 1931), Vol. 22, No. 2, pp. 65-66.

Electric Welding, Arc. Arc Welds Cut Repair and Maintenance Bills. B. S. Havens. Mill and Factory Illustrated (March, 1931), Vol. 8, No. 3, pp. 40-43. Examples of different applications.

Electric Welding, Arc—Europe. Arc Welding in Europe. E. D. Lacy. Am. Mach. (March 26, 1931), Vol. 74, No. 13, pp. 505-507. Application of arc welding in construction and repair work by Belgian, German and British railroads; welding practice on street railways.

Electric Welding Machines, Spot. The Dyer Bench Spot Welder. Engineering (March 20, 1931), Vol. 131, No. 3401, p. 408.

Electric Welding Used in Building of Gyroscope. The Iron Age (March 19, 1931), Vol. 127, No. 12, p. 938.

Gas Pipe Lines—Welding. Economics of Welding in Maintenance and Operation of Gas Transmission Systems. E. Larson. Gas Engr. (March, 1931), Vol. 18, No. 3, pp. 155-156.

Hydraulic Turbines—Welding. Hydraulic Turbine Repaired by Electric Welding. C. R. Reid. Power (March 24, 1931), Vol. 73, No. 12, pp. 478-479. Badly damaged Francis-type runner of 20,000 hp. unit repaired at cost of only $2,274.

Inspection of Welds in Pressure Vessels. Sheet Metal Industries (March, 1931), Vol. 4, No. 11, pp. 990-991.

Jigs and Fixtures, Welded. A Machine Tool Builder Welds Jigs. Am. Mach. (March 10, 1931), Vol. 74, No. 10, pp. 395-497.

Jigs and Fixtures, Welded. Design Features of Welded Tooling. F. W. Curtis. West. Machy. World (March, 1931), Vol. 22, No. 3, pp. 115-118. Practical examples illustrate advantages of welding with regard to cost reduction, savings and weight, and greater strength; procedure of making welded tools.

Locomotive Crankshafts—Welding. Arc Welding Broken Crankshafts. Welding Engineer (March, 1931), Vol. 16, No. 3, pp. 36-38.

Locomotive Repair Shops—Welding. Autogenous Welding on Locomotives. Ry. Jl. (February, 1931), Vol. 37, No. 2, pp. 16-18.

Manganese Steel—Welding. Welding High Manganese Steels. Welding (March, 1931), Vol. 2, No. 3, pp. 169-171.

Metals—Hard Facing. Hard-Facing in Industrial Fields. W. A. Wissler and A. V. Harris. West. Machy. World (March, 1931), Vol. 22, No. 3, pp. 119-121.

Monel Metal—Welding. Some Practical Notes on Welding Monel Metal. Machy. (Lond.) (March 5, 1931), Vol. 37, No. 960, pp. 733-734.

Motor Trucks, Tank. Use of Aluminum Truck Tanks Profitable Where Weight Limit Is a Factor. J. C. Chatfield. Nat. Petroleum News (Jan. 28, 1931), Vol. 23, No. 4, pp. 25-26.

"One Piece" Welded Building. The Fusion News, issue No. 20, pp. 17 and 19-20. Welded sheeting placed longitudinally furnishes all the bracing required for the building.

Oxy-Acetylene Cutting Applications. Oxy-Acetylene Tips (March, 1931), Vol. 10, No. 3, pp. 51-55. Application in scrap yards and in shape cutting for production.

Oxy-Acetylene Welding. Cutting Overhead with Oxwelding. R. E. Fritsch. Plumbers Trade Jl. (March 15, 1931), Vol. 15, No. 6, pp. 12-13 and 45. Progress of oxy-acetylene pipe welding and prophecy as to future in field of plumbing and heating.

Oxy-Acetylene Welding. Welding with an Additional Reducing Flame. M. R. Meslier. Sheet Metal Industries (November, 1930), Vol. 4, No. 7, pp. 574-576.

Oxy-Acetylene Welding of Corrosion Resisting Metals and Alloys. W. B. Miller. Sheet Metal Industries (March, 1931), Vol. 4, No. 11, pp. 992-994.

Pipe Lines—Electric Welding. Pipe Line Welding. W. T. Graham. Welding Engr. (February, 1931), Vol. 16, No. 2, pp. 42-44.

Pressure Vessels—Heads. The Strength of Welded Bull Plugs. F. E. Wertheim. Mech. Engr. (April, 1931), Vol. 53, No. 4, p. 310.

Pressure Vessels—Testing. Welded Steel Drums for Scout Cruisers. J. C. Hodge. Metal Progress (March, 1931), Vol. 19, No. 3, pp. 40-45.

Pressure Vessels—Welding. Proposed Specifications for Fusion Welding. Mech. Eng. (March, 1931), Vol. 53, No. 3, pp. 230-232. Proposed revisions and additions to code for unfired pressure vessels for fusion-welded construction.

Repairing Manganese Track Work by Welding. H. H. George. Electric Traction (March, 1931), Vol. 27, No. 3, pp. 125-127.

Sheet Metal Welding Formulæ. Sheet Metal Industries (March, 1931), Vol. 4, No. 11, pp. 984, 986 and 989.

Shipbuilding—Electric Welding. Electric Welding in Ship Construction. Engineering (Feb. 20, 1931), Vol. 131, No. 3397, pp. 274-275. Editorial review of paper before Institution of Engineers and Shipbuilders in Scotland, affording evidence of merits of electric welding, of its limitations, and of existing need to remove some, at any rate, of restrictions upon its more general application.

Ships—Maintenance and Repair. Oxy-Acetylene in Ship-

yard Work. J. W. Owens. Welding Engineer (March, 1931), Vol. 16, No. 3, pp. 46-48.

Solders, Silver. Engineering Silver Solders. Metallurgist (Supp. to Engineer) (Feb. 27, 1931), pp. 23-24.

Steam-Electric Power Plants—Construction: Fabrication and Erection of 3000-Ton Steel Structure at Yallourn, Victoria. Commonwealth Engr. (Feb. 2, 1931), Vol. 18, No. 7, pp. 241-246.

Steel Castings—Welding. Steel Foundry Welding. V. G. Pearson. Foundry Trade Jl. (Feb. 26, 1931), Vol. 44, No. 758, pp. 162-164.

Structural Steel Welding. The Field of Welding. E. Gassow. Assoc. Chinese and Am. Engineers Jl. (January, 1931). Vol. 12, No. 1, pp. 11-17.

Structural Steel Welding—Germany. The Application of Welding to Steel Constructional Work in Germany. O. Bondy. Engineering (March 6, 1931), Vol. 131, No. 3399, pp. 322-323.

The Effect of Contamination by Nitrogen on the Structure of Electric Welds. L. W. Schuster. Journal of the American Society of Naval Engineers (February, 1931), Vol. 43, No. 1, pp. 140-147.

The Manufacture of Carbon and Graphite Welding Electrodes. Hugh H. Wikle. The Fusion News, issue No. 20, pp. 15-16 and 21.

The Microstructure of Iron and Steel. Mechanical and Welding Engineer (Feb. 20, 1931), Vol. 5, No. 7, pp. 44-49.

Structural Steel Welding. The Application of Electric Welding to the Strengthening and Erection of Steel Structures, E. P. S. Gardner. Junior Instn. Engrs.—Jl. and Rec. Trans., Vol. 40, 1929-1930, pp. 519-538.

Tanks—Welding. Electrically-Welded Tanks at a Distillery. Engineer (Feb. 6, 1931), Vol. 151, No. 3917, p. 158.

Welded Steel Structures. Wider Adoption of Structural Welding Depends on Comparative Costs, A. F. Davis. Metal Progress (February, 1931), Vol. 19, No. 2, pp. 59-62.

Welding a Skyscraper, F. P. McKibben. The Welding Engineer (February, 1931), Vol. 16, No. 2, pp. 27-31. Details of design; Erection methods and inspection procedure followed in building the 19-story welded building in Dallas, Texas.

Welding in Home Building, E. H. Ewertz. The Welding Engineer (February, 1931), Vol. 16, No. 2, pp. 39-41. A practical and flexible type of design for welded steel framework for small and medium sized residences.

Welding Problems—II, P. Gibbons. Sheet Metal Industries (February, 1931), Vol. 4, No. 10, pp. 904 and 906.

Welding Standardization. Welding Standards. Metallurgist (Supp. to Engineer) (Jan. 30, 1931), pp. 1-2.

Welds—Strength. The Strength of Arc-Welded Joints, F. R. Freemen. Engineering (Feb. 6, 1931), Vol. 131, No. 3395, p. 192. Abstract of paper before Instn. Civil Engrs., previously indexed from their Minutes of Proc., No. 4808, 1930-31.

Welds—Testing. Computing Fillet Weld Stresses, C. H. Jennings. Welding (February, 1931), Vol. 2, No. 2, pp. 101-104. Development of three methods for computing fillet weld stresses; conventional method, principal stress method and resultant force methods; tensile test results are compared with calculated stresses in different size welds.

Welds—Testing. Tests on Electric Arc Welded Lap Joints, R. P. Davis and L. V. Carpenter. W. Va. Univ. College Eng.—Research Bul. (November, 1930), No. 7, Series 16, No. 2, 16 pp. Investigation to check work of other investigators and to obtain further information and data upon which safe unit working stresses for design of lap-welded plates can be based when using arc type of welding.

The Welder. A monthly magazine devoted to Electric Arc and Oxy-Acetylene Welding. Published by Murex Welding Processes, Limited, of London. Contains articles on The Design of Welded Steel Structures. Railway Crossings Reinforced by Welding. Welding for the Steel Foundry. Welded Tanks for a Distillery. The Tallest Welded Building. All Welded Steel Barge; and others.

Thermit Welding Practice in England. E. D. Lacy. Welding (March, 1931), Vol. 2, No. 3, pp. 177-179. Application of thermit welding procedure with particular regard to rail joints and results of series of tensile and bending test.

Tubes—Welding. Making and Repairing Coils. J. C. Coyle. West. Machy. World (February, 1931), Vol. 22, No. 2, pp. 67-68.

Welded Steel Structures. Method of Erecting Welded Arch Buildings. R. I. Graveley. Welding (March, 1931), Vol. 2, No. 3, pp. 175-176.

Welded Steel Structures. Welding a Skyscraper. F. P. McKibben. Welding Engr. (February, 1931), Vol. 16, No. 2, pp. 27-31. Part II in March, 1931, issue of Welding Engineer.

Welding. Symposium on Welding. Am. Soc. Testing Matls. Preprint, for mtg. March 18, 1931, pp. 5-90. Papers included are: General Survey of Welding Processes, F. T. Llewellyn; Welding Processes Applicable to Aluminum, W. M. Dunlap; The Quality of Materials for Fusion Welding, C. R. Texter and F. N. Speller; Modern Applications of Arc Welding, A. M. Candy; Stethoscopic Examination of Welded Products, J. R. Dawson; Magnetic Methods of Testing Butt Welds, T. R. Watts; Fatigue and Impact Testing of Welded Products, T. M. Jasper; Welding Inspection, R. Kraus.

Welds—Corrosion. The Effect of Contamination by Nitrogen on the Structure of Electric Welds, L. W. Schuster. Iron and Steel Inst. Jl., Vol. 122, No. 2, 1930, pp. 249-278 and (discussion) 279-288, 35 figs. on supp. plates.

Welds—Strength. Experiments on Gas Welded Structural Joints, J. R. Griffith. Mech. Eng. (March, 1931), Vol. 53, No. 3, p. 227.

Welds—Strength. Fillet Welds Determined Graphically. J. R. Griffith. Welding (March, 1931), Vol. 2, No. 3, pp. 163-165. Method of finding size and length of fillet welds for member in pure tension or compression by means of nomographic charts.

Welds—Testing. Certifying Welds. H. L. Whittemore. Welding Engr. (March, 1931), Vol. 16, No. 3, p. 49. Suggestions regarding subjecting of welding procedure to engineering control and assurance of certificates or documents testifying to quality of welds.

Welds—Testing. Fatigue Properties of Welds. J. B. Johnson. Welding (March, 1931), Vol. 2, No. 3, pp. 159-162 and 165.

SUBSCRIPTION TO JOURNAL

Companies desiring additional copies of the Journal may obtain same at a subscription of $5 to those in the United States and Canada; $10 for foreign countries and $6 to foreign libraries. In order to have the volume complete it is suggested that subscriptions be sent in at once to American Welding Society, 33 West 39th Street, New York.

Biography Authors

(*Continued from page 4*)

Frederick Ray, author of the paper on "High Tensile Atomic Hydrogen Arc Welds in Alloy Steels," studied mechanical engineering at Stanford University; physics and mathematics at Columbia and Harvard universities. He has been draftsman and designer for the Byron-Jackson Machine Works, Abner Doble, and Fulton Iron Works, all of San Francisco. He then became engineer of Centrifugal Pump Department of the Henry R. Worthington Co., 1902 to 1906; and chief engineer of the Alberger Pump Co., 1906 to 1914. He became consulting engineer in 1914 and since that time has been occupied to a considerable extent in connection with the development of expansion joints and other products.

D. C. Tennant, author of the paper on "Some Examples of Welding in Structural Steel Work," is an engineering graduate of the University of Toronto, receiving the B. A. Sc. degree there in the year 1900. He is a member of the American Society of Civil Engineers and of the Engineering Institute of Canada, of which latter he was chairman of the Montreal Branch during the past year. He has been with the Dominion Bridge Company in Montreal ever since graduation, in the structural department. which includes a great variety of work, and has for some years been structural engineer of the company.

J. H. Zink, author of the paper on "Welding of Heating and Industrial Piping," is president of the Heat and Power Corporation. Mr. Zink has been an outstanding figure in the welding industry and has been closely identified with the progress made in the welding of heat and power piping. He was largely responsible for the present standards of workmanship of the Heating and Piping Contractors' National Association. He is chairman of the Committee on Welding and the Editorial Committee of this organization.

Welding Symposium at Lehigh University

An all-day symposium was held at Lehigh University on March 27. The program began at 9:30 a. m. with papers and discussion on "Processes of Welding in General" and on "Testing the Welds," by Prof. Comfort A. Adams, Harvard University; Gilbert E. Doan, Lehigh University, and others.

In the afternoon there were demonstrations of radiographic examination by gamma rays and testing of welds made by atomic hydrogen, butt, gas and thermit welding processes.

There were also demonstrations of automatic arc and spot welding and of the mechanical testing of welded specimens.

In the evening J. C. Hodge, of the Babcock & Wilcox Company, presented a paper on welding. This was followed by an exhibition of the radiographic films from the afternoon tests.

Why Are Welded Boiler Drums So Long in Coming?

(*Reprinted from March 1, 1931, issue of Power Plant Engineering*)

Contrary to popular opinion, agitation for welded boiler drums and pressure vessels covered by code goes back many years. Preliminary hearings were held before the A.S.M.E. Boiler Code Committee as far back as 1911 and the first Boiler Code edition in 1914 provided for forge welding with an ultimate strength of 28,500 lb. per sq. in. in 47,000 to 55,000 lb. per sq. in. steel plate. This was allowable stress retained in the 1918 edition, but was increased to 35,000 lb. per sq. in. in the 1924 edition. That fusion welding was seriously considered is shown by the sentence definitely forbidding its use except in cases where the load was carried by other construction. The present proposed specification for fusion welding of drums or shells of power boilers was published in March, 1930. It provides for maximum working stress in a welded joint as one-fifth of 80 per cent (or 16 per cent) of the minimum specified tensile strength of the plate. Many feel that this should be increased to 90 or 100 per cent. In Germany, practice for forge welding ranges from 0.3 to 0.9 (depending upon the method used) and for fusion welding from 0.5 to 0.65 (depending upon the subsequent annealing).

Progress in this direction has been less rapid than it might have been, but much of this delay can be attributed to the attitude of the welding companies and the apparent mistrust and suspicion with which they regard one another. Each one independently plowed through the same field to discover the same elementary principles and reach practically the same goal. They guard with jealous care what is probably an empty hat and discuss with infinite caution exhaustive tests apparently made only to enable them to tell of the millions spent on their development work.

So shackled with words, progress has been slow, and the reason for the delay is clearly pointed out by the following address recently made before the A. W. S.: "Manufacturers of pressure vessels, some gas welded, some arc welded and some resistance welded, come to these meetings and tell of the great numbers of such vessels which they each make each year and of the many millions of dollars of value represented by them. The pressure vessel committees, deeply conscious of their responsibilities in establishing rules to govern this important industry, plan researches which would cost a few tens of thousands of dollars. The manufacturers and users and others who would presumably be interested are asked to contribute to the cost of these researches.

"Out of the many dozens of firms approached, perhaps about five firms undertake to contribute to the costs, but to the extent of only a few hundreds of dollars each. This is all that small firms ought to be expected to contribute, but is disappointing in the case of the important concerns whose representatives in the discussion of papers never mention a sum less than a million dollars when describing their research activities. There is a striking contrast between the general suggestions in the discussion of papers that many of the firms are spending millions to put the final touches of perfection on their wonderful products and the ultimate admission that very few of them will put up even a few hundred dollars apiece to determine elementary things, which it is absolutely essential to know, if guesswork is to give place to reasonable certainty."

SECTION ACTIVITIES

BOSTON

About forty members of the Boston Section attended the March meeting, which was held at the Watertown Arsenal through the courtesy of the commanding officer, Colonel Dickson. This meeting was held in the afternoon, the members being conducted through the various shops where anti-aircraft gun parts were fabricated and assembled into the finished product. The use of gas cutting for obtaining the many shapes required in the production work was seen in operation.

The explanation for the excellent welding obtained at the Arsenal was given in the description of the X-ray examination of welds as made there. Many interesting X-ray views were shown. Physical testing of welds and the results obtained by photomicrograph and macroscopic examination were explained, and examples shown. The meeting was extremely interesting, and the members were well repaid for the time spent there.

The April meeting will be on April 15 in Tremont Temple and will be a joint meeting of the Engineering Societies of Boston. R. V. Jacobs, of the

Goodyear Tire & Rubber Company, Inc., Akron, Ohio, will speak on "Lighter Than Air Craft."

CHICAGO

The March meeting of the Chicago Section was held Friday, March 6, at the Palmer House Hotel, at which time G. Van Dyke, of Joseph T. Ryerson & Son, Inc., talked on the subject "Special Corrosion Resisting Steels." While Mr. Van Dyke's paper did not in general cover the subject of welding chrome nickel alloys, the facts that he presented were of such a nature that those who weld them gathered considerable information that will help them in working with these metals. Mr. Van Dyke's paper was of such interest that the 100 men who were in attendance stayed well after 10:30 asking questions and discussing the problems of welding corrosion resisting steels.

As usual the meeting was preceded by a dinner, which has been one of the features of the Chicago Section meetings during the past winter.

CLEVELAND

On Thursday evening, March 26, the Cleveland Section had the pleasure of hearing Harry Reed, Safety Expert of the Chicago Eye Shield Company, present a paper on "Head and Eye Protection." This was the first safety meeting held in Cleveland by the Society and a successful one. A lively discussion followed the presentation of the paper.

DETROIT

The March meeting of the Detroit Section was held on the 24th. P. W. Fassler, welding engineer, gave a preliminary talk on the purpose of his paper, "Twenty-Five Years of Electric Welding." The paper was read by Mr. LaBadie, his electrical assistant. The paper included What Is Welding, How to Weld, Butt, Flash, Spot, and Seam Welding. Following this interesting and instructive paper a discussion of thirty minutes followed on the electrical characteristics of resistance welders.

The Tellers' Committee reported the following officers elected for year 1931-32:

Chairman—C. A. Bowlus.
Vice-Chairman—E. P. Jeffrey.
Secretary-Treasurer—M. P. Bailey.
Executive Committee:
H. P. Doud, two years.
J. B. Manor, 1 year.
Joseph Mattex, Jr., two years.
Guy F. Allen, 1 year.

LOS ANGELES

The regular monthly meeting and dinner was held at the hall of the Oil Equipment Exposition in Compton on March 17th. The exposition was in full swing, and the members of the Society had an opportunity to inspect all the exhibits, which were extremely interesting to those connected with the oil industry.

After the dinner the meeting was brought to order, minutes read and approved, and the meeting thrown open for a short discussion of welding problems confronting members. After this discussion, motion pictures showing the manufacture of steel pipe were exhibited through the courtesy of the National Tube Company. The meeting was adjourned early in order to allow members to inspect the exhibits at the exposition.

NORTHERN NEW YORK

The Northern New York Section held a joint meeting with the Union College Chapter of the A.S.C.E. and the Schenectady Sections of the A.I.E.E. and A.S.M.E. in the old Chapel at Union College, Schenectady, on March 11th.

Prof. F. P. McKibben, consulting engineer, spoke on welded building construction, particularly on the building recently erected in Boston for the Edison Illuminating Company. He also spoke of methods of relieving stresses in existing structures by replacing the members under strain by arc welded construction.

Attendance at this meeting was approximately 200.

PHILADELPHIA

James W. Owens, director of engineering, Welding Engineering and Research Corp., spoke on "Residual Stresses" at the March 16th meeting of the Philadelphia Section.

At the April meeting it is expected to have J. H. Churchfield, of the South Philadelphia Works, Westinghouse Electric & Mfg. Co., talk on "Welding Applied to Marine Equipment." This will be the annual meeting of the Philadelphia Section.

PITTSBURGH

The members and friends of the Pittsburgh Chapter met with the American Society for Testing Materials in an all-day session in the William Penn Hotel, Wednesday, March 18, at which time one of the most complete programs on welding in general was presented. The morning session was devoted to papers and discussion on "Process," "Materials" and "Applications" of welding, while the afternoon session covered the "Inspection and Testing of Welded Products."

All papers were very well presented and considerable discussion, both prepared and extemporaneous, on the various phases of welding resulted.

G. H. Danforth, formerly secretary of the Pittsburgh Chapter, acted as chairman at both sessions.

Many members and friends of the Chapter also attended the Regional Dinner closing the session and remained to enjoy the entertainment provided by the Westinghouse Electric & Mfg. Co.

Plans for the regular meeting, April 22, are now being worked out, and it is proposed to have two well-known speakers at that time.

PORTLAND

A meeting of the Portland Section was held on March 16. About fifty people were present. Prof. S. Graf, director of the Engineering Experiment Station at Oregon State College, and professor of physics at the same institution, presented a paper covering the various phases of welding, including the welding of steel, iron and alloy metals and duralumin. The metallurgical aspects of welds were discussed and the theory explained.

SERVICES AVAILABLE

Opportunities.—The Society is glad to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN.

Services Available.—Under this heading brief announcements (not more than seventy-five words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period, names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Society's Office not later than the thirtieth of the month if publication in the following issue is desired. *ALL REPLIES should be addressed to the number indicated in each case and mailed to the Society headquarters.*

A-126. Tank and plate shop superintendent. Graduate M. E. Fifteen years on design and construction of welded pressure vessels. Recent experience on pressure vessel welding of chrome-nickel alloys, stainless steels, etc.

A-127. Gas welder desires position. Experienced.

A-128. Electric welder desires position. Experienced.

A-129. Sales engineer desires position. Has had technical education as electrical engineer, 4½ years' sales experience with G. E. Company, experience in the electrical contracting field, and salesman of apparatus and gases for the welding industry; also as general purchasing agent for large manufacturer of oxy-acetylene equipment.

LOCAL TELEPHONE SERVICE ONCE COST

$240 A YEAR

In 1879, the New York telephone directory was a card listing 252 names. There were no telephone numbers, nor any need for them. When you telephoned, you gave the operator the name of the person you wanted. Service was slow, inadequate and limited principally to people of wealth. The cost of a single telephone was as high as $240 a year.

Today, you can talk to any one of hundreds of thousands of telephone users for a fraction of what it then cost for connection with less than three hundred. Every new installation increases the scope and value of the telephones in your home or office.

Twenty-four hours of every day, the telephone stands ready to serve you in the ordinary affairs of life and in emergencies. In the dead of night, it will summon a physician to the bedside of a sick child. Men transact a great part of their business over it. Women use it constantly to save steps and time in social and household duties. In an increasing number of ways, it helps to make this a united, more active, more efficient nation.

Simply by lifting the receiver you become part of a nation-wide communication system that uses 80,000,000 miles of wire, and represents an investment of more than $4,000,000,000. Yet the cost of local service is only a few cents a day.

Subscribers who look back over the month and consider what the telephone has meant to them in convenience, security and achievement are quick to appreciate its indispensable value and reasonable price.

Frequently you hear it said—"The telephone gives you a lot for your money."

★ *AMERICAN TELEPHONE AND TELEGRAPH COMPANY* ★

Mention the "Journal of the American Welding Society."

YOU CAN DO IT BETTER WITH TORCHWELD

When using Torchweld torches and regulators you will find "Operating Safety." No matter what your requirements are as to type or style, Torchweld equipment will fully meet them. It is their design that assures safety.

You can install Torchweld with complete confidence of their results.

TORCHWELD

Write for Catalog No. 29.

TORCHWELD EQUIPMENT COMPANY

224 N. Carpenter St. Chicago, Illinois

*ELKONITE** DIES AND ELECTRODES

FOR RESISTANCE WELDING

Last 10 to 80 times longer than other die material.

Make cleaner, better welds, with less shrinkage.

Weld parts together with a fine degree of accuracy enabling smaller parts to be machine finished *before* welding. Increase the factor of safety in fabrication.

Can be used for high speed automatic operation.

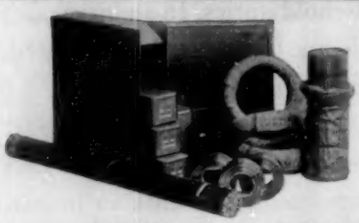
Booklet on request.

ELKON

Division of P. R. MALLORY & CO., INC.

New York—Detroit—Indianapolis

* *Reg. U. S. Pat. Off.*



WELDING-RODS

Try SENECA BRAND

for Gas and Electric purposes—
RODS made from select analysis stock—insuring uniform quality

SPECIFY SENECA BRAND

Manufactured by

THE SENECA WIRE & MFG. CO.

FOSTORIA, OHIO

ESTABLISHED 1905

IRON STEEL QUALITY SERVICE WIRE "SENECA" TRADE MARK

Our Advertisers Are Supporting the Society.